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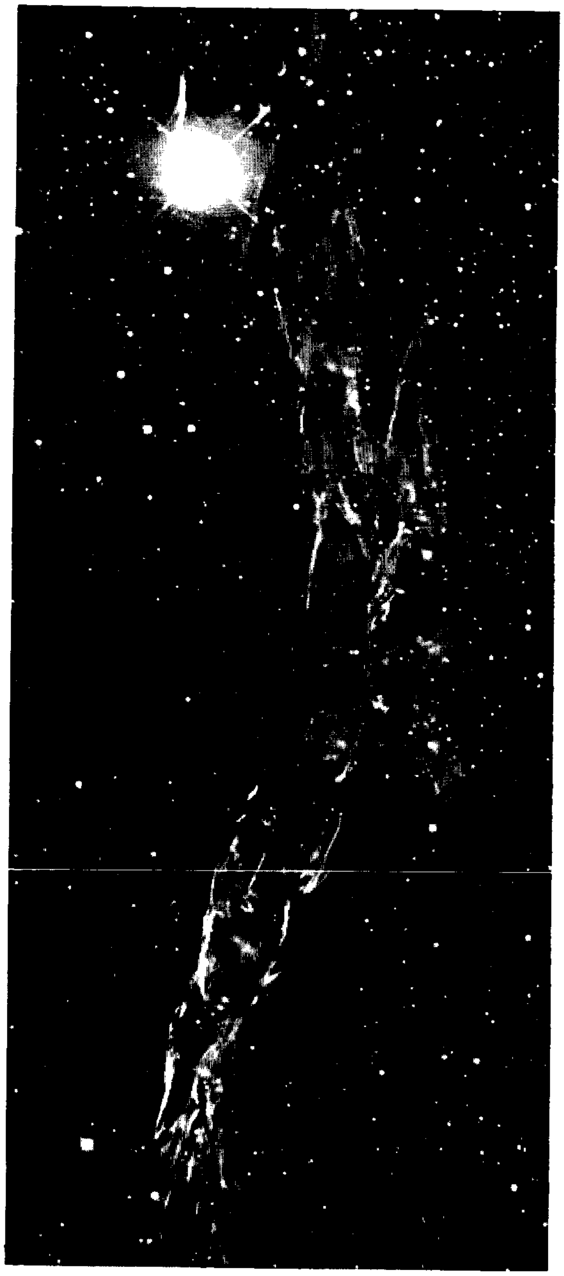

ADVANCED ANTENNA SYSTEM FOR J.P.L. DEEP SPACE INSTRUMENTATION FACILITY

NORTH AMERICAN AVIATION, INC., COLUMBUS, OHIO

ABSTRACT

Rapid advances in deep space explorations by the National Aeronautical and Space Agency make desirable a corresponding increase in the communications capability of the Deep Space Instrumentation Facility operated by the Jet Propulsion Laboratory. North American Aviation, Inc., Columbus Division, proposes to conduct a four month design feasibility study of an Advanced Antenna System which will provide this increased communications capability. This technical report describes the NAA concept, discusses the effects of the specified performance requirements on design parameters, shows the engineering problems which must be solved to provide a working design, and indicates the approach to be taken by North American Aviation, Columbus Division. The facilities, personnel, previous related experience of NAA in antenna design, microwave feed systems, design and fabrication of large structures, and related skills are described in the second volume of the two-volume proposal (NA60H-616).

Based on this experience, and investigations during the preproposal period, the concept advanced by NAA Columbus is that of a 270 foot Cassegrain system. The major reflector is azimuth-elevation mounted and counter-balanced so that deflections of the mounting structure cannot contribute to pointing errors. The frequency of reflector resonance will be above three cycles per second. The reflector is firmly held at four points around the third of five concentric rings, and the same points anchor the minor reflector which illuminates the 270 foot paraboloid.

Rigid mounting of the feed at a point between the apex of the paraboloid and the hyperboloid reduces the size of the minor reflector, and the consequent aperture blocking, while permitting rapid interchange of the feed systems.

The solid major reflector surface and the focal length to diameter ratio of 0.3 were chosen to reduce system susceptibility to the noise temperature of the earth or other disturbing influences off the side or rear of the antenna.

The antenna is supported on a truncated-conical concrete pylon for 360° azimuth rotation and 182° elevation-angle travel, as "plunging" capability is considered of great importance. A hydrostatic azimuth bearing reduces to a negligible value the static friction which impairs low-rate tracking of large antenna structures mounted on other types of bearings. The large volume in the hollow pylon can be put to use for housing part of the electronic subsystems, personnel, or storage of supplies.

Preliminary cost estimates were made for a number of possible mounting arrangements. The recommended approach represents a potential saving of approximately a million dollars over the next best design.

The recommended mounting concept permits installation of the transmitter output stages and receiver preamplifiers within a few feet of the actual feed. The short waveguide run, plus elimination from the feed of virtually all dielectric material reduces to a practical minimum the losses which would otherwise tend to raise the total effective antenna noise temperature.

Considering the effects of dead weight loading and wind deflections, it is shown that the proposed antenna concept approaches the ultimate in size which can be used to provide the desired gain and satisfy the other specification requirements in the various modes of operation. The factors governing the optimization to be performed during the proposed study are discussed.

A significant improvement in communications capability results from 11 db more forward gain (than would be realized by the 85-foot Goldstone antenna operated at S-band) plus a 1½ db reduction in system noise level.

The discussions in this report, supplemented by the combined skills, experience, facilities, and manpower described in Volume II (NA60H-616) are submitted by the Columbus Division of North American Aviation, Inc. as evidence of a sound approach upon which the proposed design feasibility study can be accomplished and of outstanding capability of the contractor to achieve the objectives defined by JPL in the succeeding phases.

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I. SCOPE OF PROPOSAL

A. GENERAL

Included in this technical proposal are discussions on the following subjects:

Reasons for choice of the particular antenna type.

Design, fabrication, transportation, erection, and operating problems of this antenna type.

Proposed approaches to solution of these problems during the Phase I study.

Variables to be studied in achieving an optimum design for the DSIF application on the basis of performance vs. cost.

Incorporated in a separate volume (NA60H-616) is information on the qualifications of the contractor, planned use of manpower and facilities during the study, and estimated cost of the design study phase.

It is understood by this contractor that the purpose of the Phase I design study is to establish that the proposed concept can provide the desired 6 to 12 db. improvement in DSIF communications effectiveness at a reasonable cost, to provide a preliminary antenna system design, and detailed specification applicable to the procurement effort of Phase II.

During the work of the design study, this contractor will analyze the relationship between antenna system communication effectiveness at the (6 - 12 db) increased gain, and cost. This analysis will be evaluated separately, when the system is used as (1) a transmitter and (2) a receiver. Preliminary design drawings will be prepared for critical elements such as major bearings, structures, antenna feeds, and data system components. Technical data included shall be adequate to establish feasibility of the design. Sketches will be included which will aid in visualizing major operational problems. Fabrication, transportation, erection and acceptance testing methods and problems will be treated in great detail.

B. SCOPE OF PHASE I EFFORT

The scope of work of the Phase I design study as proposed by North American Aviation includes the following:

1. Electromagnetic and Electronic

a. Design and Optimization Studies

(1) Antenna Radiation Performance

Antenna patterns will be calculated (using digital computer techniques) and analyzed for gain, sidelobe levels, and noise temperature as a function of basic microwave design. Off-axis feed patterns will be derived in accordance with simultaneous lobing requirements. The size of the hyperboloidal reflector will be reduced to the smallest practical size. The results of this optimization program will be compared with results of representative measurements made on a 30 foot parabolic reflector at X-band.

(2) Effects of Manufacturing Tolerances and Deflections on Antenna Performance

Effects on antenna patterns will be calculated for deflections of the major and minor reflectors caused by manufacturing tolerance irregularities, dead weight loads, thermal stresses, and wind loads. Parameters of interest are beamshift, gain, sidelobe levels, and noise temperature.

(3) Antenna Feed Systems

Optimization and integration of the transmit-listen and tracking feed system into the antenna design will be accomplished.

(4) Overall Antenna System Error Analysis

Contributions to the command pointing and readout errors will be analyzed and tabulated. Sources of such errors are:

(a) Structural deflections
(b) Bearing imperfections
(c) Digital position data errors
(d) Control system static friction

(5) Reliability of Data System

The statistical reliability of the data system electronic equipment will be calculated. The components of interest are the digital read-out system, command position error generators, and scan function generators.

(6) Antenna Gain vs. Cost

Studies of antenna gain and communications effectiveness vs. antenna size and cost in the range of 6 - 12 db over the Goldstone 85 foot antenna will be conducted for transmitting and listening modes.

b. Preliminary Design and Specification

Preliminary designs and specifications will be prepared for the following equipment:

(1) Digital Readout Data System and Command Position Error Generator.

(2) Microwave Optical Design of Antenna

(3) Feed Designs

Transmit-Listen
Simultaneous Lobing

(4) SHA-Declination to Azimuth-Elevation Converter

(5) Scan, Position, and Rate Function Generators

Slew Mode Generator
Elliptical Spiral Acquisition Generator
Saw-tooth Acquisition Generator
Celestial Tracking Rate Generator
Manual Rate Generator

(6) Test Fixtures and Test Equipment

Boresight Equipment
RF Test Equipment

2. Control Systems

a. Design and Optimization Studies

(1) Tracking Rates vs. Cost

Performance trade-offs between prime mover and drive system design vs. system cost for equipment required to achieve tracking rates ranging between minimum acceptable and design goals will be studied.

(2) Prime Mover Options

The relative merits of electric and hydraulic prime movers will be studied. Parameters of concern are:

(a) Speed
(b) Acceleration
(c) Noise
(d) Heat
(e) Life
(f) Rate Problems
(g) Cost
(h) Cogging (electric)

(3) Pointing Accuracy

Optimization studies will be conducted with parameters affecting pointing accuracy of the antenna system. These parameters are:

(a) Servo Gain
(b) Bandwidth
(c) Stiction
(d) Backlash
(e) Elastance
(f) Transducers
(g) Torque Gradient
(h) Auto Tracking Requirement
(i) Slew and Scan Requirement

Cost of achieving accuracies in the range from minimum acceptable to design goals will be investigated.

(4) Bearings

Bearing options will be studied with parameters of performance weighed against cost.

b. Preliminary Design and Specification

Preliminary designs and specifications will be prepared for the following:

(1) Control Components

(2) Drive Motors

(3) Gearing

(4) Major Structural Support Bearings

3. <u>Structural</u>

a. Design and Optimization Studies

Design optimization studies will be performed on the following structural components and parameters:

(1) Reflector surface sandwich

(2) Reflector ring structures

(3) Auxiliary reflector structure

(4) Reflector materials

(5) Thermal deflections as function of design

(6) Number of Pick-up points on reflector

(7) Hyperbolic reflector quadripod

(8) Feed horn cantilever

(9) Steel support structure

(a) Elevation
(b) Elevation to azimuth
(c) Elevation drive structure
(d) Azimuth drive structure

(10) Tower

(11) Base

b. Preliminary Design and Specification

Preliminary designs and specifications will be prepared for the following components:

(1) Reflector

(2) Supporting structure

(3) Counterweights

(4) Tower

II. SYSTEM CONCEPT

The NAA concept of an Advanced Antenna System for the DSIF is that of a completely trainable Cassegrain system with interchangeable feeds, a major reflector 270 feet in diameter, a minor reflector from 30 to 40 feet in diameter, associated control, programming, drive, calibration and checkout subsystems.

The antenna can be driven through 600° in azimuth and from -1° elevation angle up to zenith and down to -1° on the reciprocal bearing for maintenance access and for calibration purposes. Actual operation is limited to the region bounded by ± 35° declination planes and by the cone of 5° elevation angle. The modes of operation in this region are slew, manual position, manual rate, automatic track, slave, and sidereal drive. Elliptical spiral or sawtooth scan motions can be superimposed in the manual rate, sidereal drive, and slave modes.

The remainder of this section will describe the functional elements and components of the advanced antenna system, as conceived by NAA Columbus.

Detailed considerations, other possible approaches that were considered, and the substantiation accomplished or to be carried out during the Phase I study are discussed in Section III of this report in detail. In the remainder of this section, figures in parentheses refer to paragraphs of Section III for detailed discussion.

A. ELECTRONIC SYSTEM

1. Microwave Optics

An azimuth-elevation mounted paraboloid with Cassegrain optics is the NAA choice to satisfy the gain and low sidelobe requirements of the application. The major reflector of the Cassegrain system (III-A-1) is 270 feet in diameter, with a solid surface and with a f/d (focal length to diameter) ratio of 0.3. The primary feed is mounted about midway between apex and focus of the paraboloid. The minor reflector (hyperboloid) is reduced in size by the forward displacement of the feed. Illumination of the major reflector is tapered, in an approximation to the ideal distribution, to minimize sidelobes monotonically. Rigidity of the structure and certain aspects of its design (III-B-1) minimize deflections which would degrade sidelobe suppression and prevent flexure of the suspension which would introduce variable pointing errors.

A radio equipment room is located on the axis of the paraboloid between its apex and the feed. JPL-supplied transmitting and receiving equipment is located in this room and is connected to the feed by low-loss waveguide.

2. Antenna Feeds

Interchangeable feeds are provided for operation on the frequencies used for S-band or L-band transmitting and listening. Circularly polarized radiation is provided from square double ridged horns (III-A-2). The rotation sense can be changed by 90° rotation of a section of the 45° oriented waveguide. Changeover from transmission to reception requires transfer of the feed assembly from the transmitter waveguide to the receiver waveguide. These operations are accomplished rapidly by having rotatable structure between the feed support plate and a similar plate anchoring the ends of the waveguides. A bent section of guide mounted in this structure effects the transfer when the drum is rotated. Spring loading or clamping devices keep the joints tight, but allow rapid changeover without requiring removal of bolts. The transmitting and receiving waveguides approach the drum in short parallel runs. The last section of each is provided with a set of circular flanges indexed for the 90° rotation.

Replacement of the feed horn and its support plate is required when the automatic tracking mode is desired. A four horn cluster and associated duplexer provides "monopulse" operation for error-signal derivation.

Operation at L-band requires replacement of the S-band waveguides and feeds with similar hardware. Thus, the feed system comprises the following equipment for each band:

Transmitter waveguide
Receiver waveguide
Single-horn feed (used on transmit and receive)
Four-horn cluster for automatic tracking

All elements of the feed system use a minimum of dielectric material to reduce the losses which would otherwise degrade receiving system effectivity (III-A-2).

3. Boresighting and Checking Subsystem

This equipment is used during the erection, initial checking, and periodic performance checking. It establishes the geometry of the microwave optics, evaluates the systematic deviations, and enables corrections for these. Measurements made over a period of time in various antenna attitudes and under wind conditions from 0 to 30 mph will permit the evaluation of the magnitudes of errors from wind gusts.

The boresighting and checking subsystem operated in conjunction with the antenna control and programming subsystem and the approach conceived by NAA integrates these subsystems by using many portions of the equipment to perform functions of both subsystems.

Optical techniques and equipment have been selected. Angle measurements are made to 2" of arc, enabling geometry to be measured to .001". Key control points are on the top of the antenna mounting pylon, four of the suspension points on the main (third) ring of the major reflector, points on the main ring of the minor reflector, a datum point on the earth directly beneath the antenna, and a point on a collimating tower at some distance from the antenna.

During erection, the axis of the reflector system is optically established by alignment of the ground datum point, the control point at the top of the pylon, and a third point on this line produced upward. The antenna is erected in the zenith-pointing direction. Prisms at the top control point provide an optical path from the control points on the main ring up to the top and down the axis. Successive scanning of the main ring points with the prisms at two vertical distances above the pylon top determine the locations of the main ring control points. Adjustments can then be made to bring these points to their desired locations. The process is repeated on each successive ring from the center to the rim of the parabola, and for points on each ring of the hyperboloid, with new prisms in the optical path.

The purpose of the boresighting operation is to bring the RF axis of the system into parallelism with the optical axis. Stiffness of the structure prevents deflection of the optical axis or its displacement by more than a small amount (III-B-1). Static and dynamic boresighting tests will be performed to maintain the relationship of the axes to within $\pm.005°$ for all antenna attitudes. Initial static tests (III-A-1) will be made by comparison of the optical path along the antenna axis to a collimation tower with the RF path. Receiving antennas on the tower, spaced to subtend the halfpower-beamwidth of the DSIF antenna, permit location of the RF axis. Adjustment of feed position brings the RF axis parallel to the optical axis. A third antenna (between the two sensor antennas) monitors the main lobe amplitude and serves as optical target.

A reciprocal process with energy supplied to the center antenna on the tower, permits alignment of the "monopulse" tracking feed. Detectors connected to the reference and error channels of the duplexer allow recording of null depth, and magnitude and linearity of slopes adjacent to the null.

Checking the boresighting at elevation angles much above horizontal requires a source of energy which is also visible. A TV system looking out the optical axis at visible stars which emit in the useful RF spectrum will be used for data at various elevations and azimuths. These data should be recorded over a period of time, analyzed, and used to establish an overall calibration.

4. Antenna Control and Programming

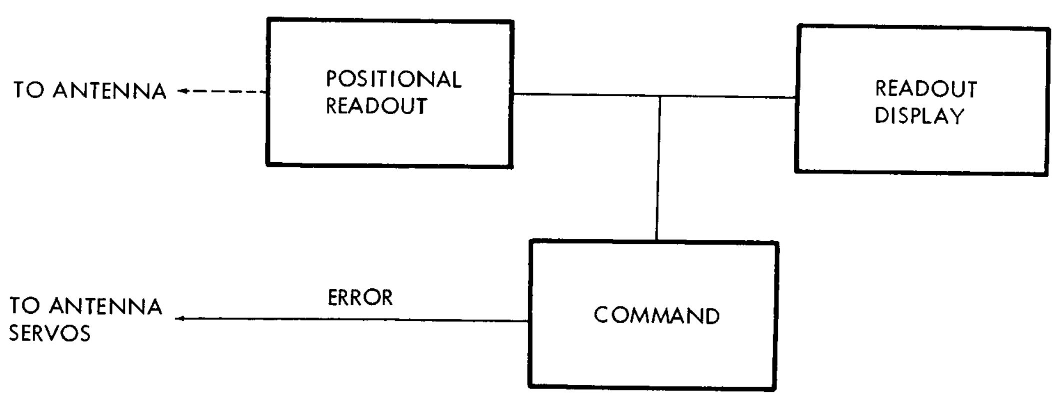
This equipment is to provide a means of accurately determining the direction of the RF axis for the antenna at all times, and generating the error signals to command the antenna positional servos. As shown in Figure II-A-1 the principal functional components are: 1) the positional read-out, 2) read-out display, and 3) the command section.

The accuracy of the overall system is heavily dependent on the accuracy of the measured antenna position. As pointed out in the paragraphs on the "Boresight and Checking Subsystem", the parallelism of the RF axis and optical axis is maintained for all antenna attitudes, within limits, by the inherent stiffness of the structure (III-B-1).

The actual positional pick-offs are two digital shaft encoders (azimuth-elevation) mounted on a scanning-tracking unit. This unit is mounted on the antenna pylon, Figure II-A-2. The control points tracked are the "target bolts" (extending through the paraboloid) which establish the optical axis. The scanning and tracking unit has four degrees of freedom. Tracking errors are derived from a process of sequentially sampling the four target image positions and comparing them with the tracker's optical axis.

The command section, Figure II-A-1 provides the necessary electronics and digital equipment to compare the actual and desired antenna positions; the output is the error signal, which is fed to the control subsystem. The methods and techniques necessary to perform the required operations are well within the state of the art.

The display, Figure II-A-1, is provided by the electronics of the two shaft encoders. The display is an array of arabic numeral indicators possessing a system resolution of 0.001 degrees. A separate storage register is required to provide, on command, positional output data in BCD form to the JPL recording and transmitting equipment. Also included in this equipment is an analog coordinate conversion servo system to convert the antenna azimuth-elevation data to SHA and declination data for display.



FUNCTIONAL COMPONENTS

FIGURE II A-1

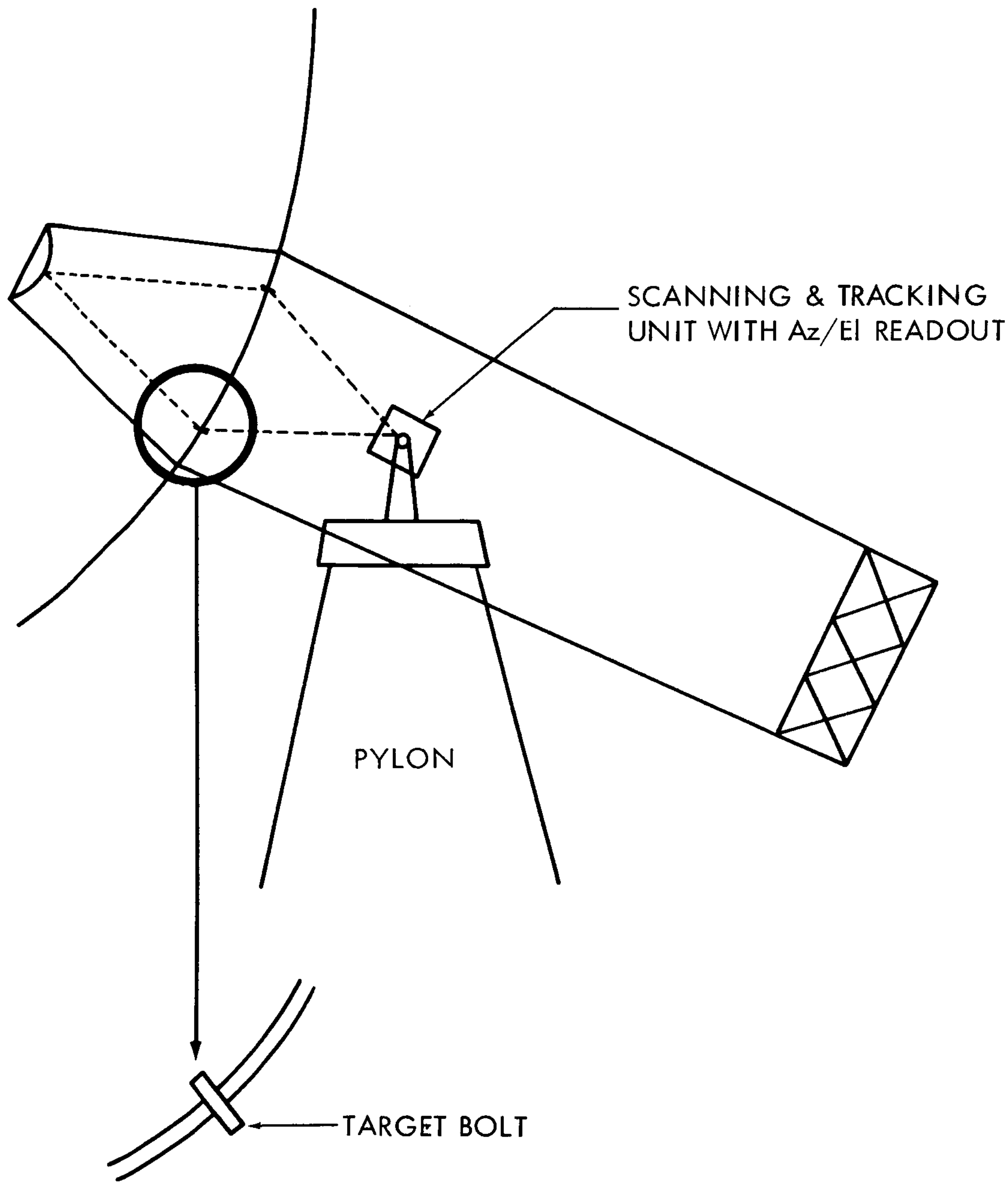


FIGURE II A-2 SCANNING - TRACKING UNIT MOUNTING

5. Noise Suppression Provisions

Electrical noise is reduced by the elimination of such notorious sources as DC motors, AC series motors, gasoline engines, conventional types of electrical switches, and fluorescent lamps. Where practical, these have been replaced by hydraulic equipment, diesel engines, and solid-state circuitry (static switches). Where replacement or elimination is excessively costly or impractical, shielding and filtering practices have been used to reduce radiated or conducted interference.

6. Fail-Safe Provisions

The final antenna design will include "fail-safe" provisions in the electronic subsystem. Functional subsystems including such provisions are the antenna drive (limit switches, minimum elevation angle interlocks on transmitter) and feed system (interlocked with transmitter during interchanges). Although not really a "fail-safe" provision, a warning system is provided to signal the approach of the antenna axis to the direction of the sun. Visual and aural warnings are provided in the control center and in other key areas.

B. STRUCTURAL SYSTEM

1. Reflector

Axial load configuration is the selected approach to the structural design of a large antenna reflector. Ultimate structural efficiency is achieved when 100% of the structure is loaded axially in resisting applied forces, as in the case of a thin spherical shell under internal pressure. This principle is used in the structure wherever geometry permits (III-B-1).

The reflector face consists of annular rows of panels, preloaded in compression by annular cables. The face is supported by a set of concentric annular rings, braced by inter-ring and intra-ring axially loaded members. These rings act as beams, the caps of which are axially loaded. The proportions of load carried by the dish and by the back-up structure are optimized for minimum deflection.

The back-up structure is stabilized against side loads, and reflector edge deflections are further reduced by a system of near-radial axially loaded beams. Certain of the inter-ring tension rods are used as diagonals for these beams. This approach uses the best available geometry of the pattern viewed along the RF axis.

The minor reflector is mounted by four braced struts, attached to the four basic reflector support points of the paraboloid. Use of materials with different thermal expansion coefficients is avoided wherever possible.

2. Mounting

Mount design is of prime importance in system performance. It is also a prime factor in control power requirements, and control system design, complexity, and cost.

Five structural concepts were evaluated before a selection was made (III-B-2).

a. Pedestal. An earthquake-resistant concrete tower, approximately 120' high, rests on concrete surfacing and footings. A steel base is mounted atop the tower. This base can be leveled, and will provide uniform support for the lower half of the azimuth bearing.

b. Azimuth and Elevation Bearing Housing. This component, a structure about 50 feet on a side, rotates in azimuth only, with its lower surface on the azimuth bearing. The elevation bearings are mounted on its sides. It contains the elevation drive motors and racks. Loads carried by the housing are uniformly distributed on the azimuth bearing. This is achieved by a shear stress distribution section in the lower portion.

c. Mount Beams. Two main beams, rotating in elevation only, pass on either side of the bearing housing. Their forward ends extend 65 feet forward of the elevation axis, where they spread into a space structure 110 feet square. The beams are trussed by triangulated structure into a rigid unit. The reflector system is supported from the forward end of this structure. Also supported by this structure, inside the feed-supporting structure, is the RF equipment room. This room is gimballed, allowing the working area to be level, while providing for short runs of rigid waveguide from transmitter output or receiver preamplifier to antenna feeds. The weight of the room and equipment is suspended by the mount beams, and does not contribute to reflector deflections.

The aft ends of the beams run 120 to 130 feet behind the elevation axis as twin cantilever counterbalance supports. These cantilevers pass either side of the pedestal when the reflector transits the zenith. Twin counterbalance weights located at the ends of the cantilevers balance the system about the azimuth and elevation axes. The beams are about 50 feet deep by 30 feet wide at the elevation bearings, and are stiff enough that their lowest resonance is above three cycles per second.

Consideration has been given to earthquake effects (III-B-2) on the supporting structure. As a result of this inquiry, the design of the reflector system only should be for resonant frequencies above three cycles per second, permitting stable control. The pedestal and support structure should be designed to avoid resonances in the region from 2.5 to 5 cycles per second, which are the strongest component frequencies in earthquake effects.

d. Mounting Provisions. At the corners of the 110 foot square, formed by the two beams and their trusses, are four reflector-mounting points. These points are coincident with the bases of the four hyperboloid support struts, and are at the natural load paths of the system. Adjustments are provided at these points. Differential thermal expansions of the mount and reflector system are absorbed by movements of the trusses connected at these points. The net effect of this design is a translation with negligible rotation of the antenna system axis and the basic mount system axis. Deadweight deflections will be programmed out, so as to have no effect on system accuracy or performance.

C. CONTROL SYSTEM

The following is a discussion of a hypothetical control system that will meet all of the requirements for the proposed antenna.

The maneuvering performance of the antenna is provided by a closed loop servo control system that incorporates hydraulic elements as the prime mover. The azimuth and elevation systems are similar, with power being supplied by hydraulic pumps located in the hydro-mechanical building. A typical schematic of one axis of control is shown in Figure II-C-1.

The control system incorporates prime movers consisting of constant displacement hydraulic motors. The motors are mounted on the azimuth axis and coupled through a conventional gear train to large diameter bull gears. Special consideration has been given to backlash in the gear train to minimize its effect on the accuracy of the total system. The motors are controlled by a conventional electro-hydraulic flow control servo valve for each axis.

The azimuth axis is mounted on a single hydrostatic bearing while the elevation axis is mounted on two conventional rolling element bearings. A hydrostatic bearing for the azimuth axis has been selected primarily to reduce the system friction and eliminate its

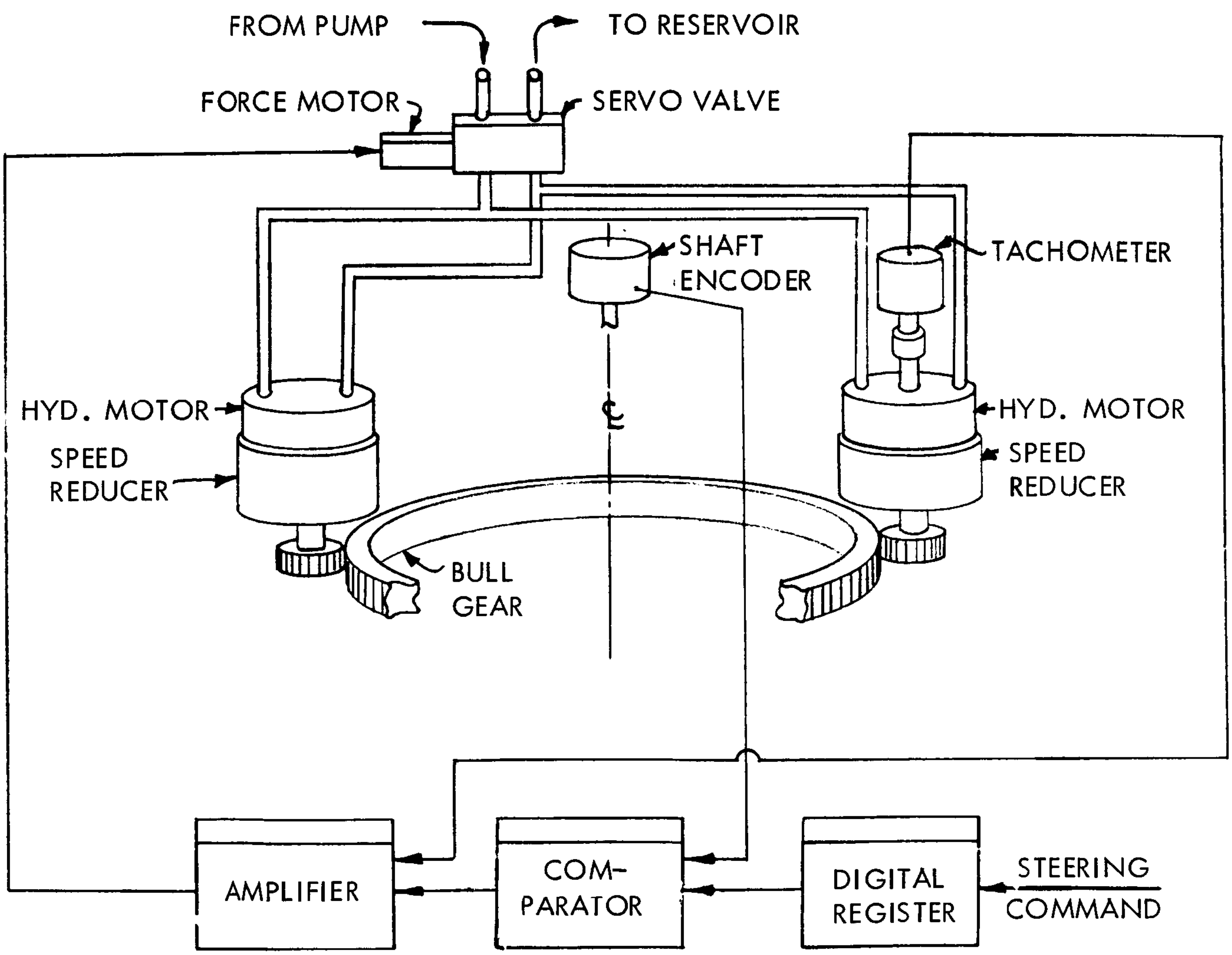


FIGURE II C-1

SCHEMATIC DIAGRAM OF
CONTROL SYSTEM

effects, making slow uniform motion possible. The rolling elements with a higher friction coefficient do not prove detrimental in the elevation axis due to their much smaller diameter. However, consideration has been given to the thermal and elastic structural deflections associated with mounting the elevation axis.

The control system is a closed loop servo, utilizing shaft encoders for position feedback, and motor tachometers for stabilization. The system incorporates an electronic digital register, comparator and amplifier to convert the digital commands to analog voltage, compare measured output with desired output, and amplify the error signal.

The control system incorporates maximum travel limit switches. In addition, mechanical buffer stops are provided in the event of a limit switch malfunction. Adequate consideration has been given the complete system to incorporate safety devices and system interlocks to prevent catastrophic effects.

The primary antenna steering control is provided by a control console located in the control building. The console incorporates push button mode switch, handwheels for manual control and a "joy stick" for slewing control. In addition to the primary console, a portable remote console is provided that incorporates position indicators and handwheel controls. Special consideration has been given to control locations and orientation to provide simplicity of operation.

The electronic components for the control system are arranged in separate racks for each axis and located in the control building. Special attention has been given the requirement for periodic testing of the components in establishing the configuration of the installation.

D. POWER SYSTEMS

The power systems supply and distribute fluid and electrical power, air conditioning, and equipment cooling for the Advanced Antenna System. Primary consideration is toward minimum cost, high reliability, and maximum simplicity consistent with the operational requirements. Completely "fail-safe" operation is of paramount importance. All service and maintenance areas are accessible and safe for personnel. Proven designs and components have been selected wherever available, to minimize required development and advancements in the state of the art.

1. Antenna Drive Power Supply

A power supply tailored to the antenna drive servo actuators is required. This equipment is located in the machinery building near the base of the antenna. Associated equipment such as hydraulic reservoir, filters, gauges, cooling, heat exchangers, etc., will also be in the machinery building. Prime power is electric (furnished by JPL).

About 250 to 300 horsepower is required to drive the antenna under maximum load conditions. Two motor-pump combinations connected in parallel supply the necessary maximum hydraulic flow. AC induction motors drive variable-volume, pressure-servo-controlled piston pumps with no gear reduction. Motor pump units are isolation-mounted and acoustically enclosed. Gauges and controls are outside the acoustic enclosure for accessibility. Remote heat exchangers and air cooling are required, since the equipment is acoustically enclosed. Hydraulic desurgers and flexible lines contribute to noise reduction. The pumps use dual pressure range compensators. The high range, about 3000 psi, is required for the maximum loads resulting from operation in winds to 70 mph. Under normal conditions, the pumps operate at about 1500 psi.

2. Lubrication System Supply

Oil is supplied under pressure for lubrication of rolling elements and bearing races, as well as for the hydrostatic azimuth bearing. This subsystem includes means for pressurization, control, filtration, and cooling. The equipment is located in the machinery building, and is powered by JPL-supplied electricity.

A variable displacement pump, driven by an induction motor, supplies oil under pressure to the bearings. Oil reservoir, controls, and filter are integral with motor and pump. Oil return is by gravity flow. Oil cooling is integrated with the drive cooling system. A large flywheel and accumulator are provided against the contingency of power failure. Dual pumps could be used at low cost, for bearing safety.

Noise reduction is accomplished by the same methods used for the antenna drive system.

3. Electronic, Equipment, and Structural Cooling

Electronic equipment, antenna drive power supply, lubrication supply, and possibly portions of the antenna structure require cooling. Convection cooling integrated with the air conditioning system is used wherever possible on the electronic equipment for minimum cost.

Acoustic enclosures are required in some areas to meet the specified 50 db acoustic noise level maximum. Liquid cooling is used where the acoustic noise problem cannot be otherwise overcome.

The lack of water at the Goldstone site has resulted in choice of liquid-to-air heat exchangers. Centralization of cooling systems is limited to individual buildings. Some integration of the conditioning/heating system with the equipment and electronic cooling system appears feasible.

4. Environmental Control

Heating, cooling, and humidity control are the functions of this subsystem. Joint contractor and JPL effort will be required for the areas and building which are JPL-supplied.

By using liquid heating/cooling with forced-air circulation, the heat removed from electronic equipment is used to augment the installation's heating system.

Humidity control is a minor design problem at Goldstone. Personnel areas and a few critical electronic equipment areas are provided with humidity control.

Isolated mountings on air-conditioning equipment, with possible acoustic treatment of duct linings, will keep acoustic noise in the RF equipment room below the 60 db limit.

5. Power Distribution System

This system picks up from the JPL 60 cycle three-phase supply, and converts, controls, and distributes the power for antenna drive, conditioning, electronics, cooling, and lighting. It includes cabling on the mount, and "wrap-up" provisions at rotating points of the antenna system. It also includes provisions to suppress radiated or conducted electrical noise.

An interlock system and warning system are provided for complete "fail-safe" operation.

Further detailed description of this system cannot be given at this time because of dependence on other subsystems not yet defined.

III. SYSTEM DETAILS

A. ELECTRONIC SYSTEMS

1. Reflector System

Because of the importance of gain and noise temperature as motivating factors in requiring a new antenna system, they are the prime quantities considered in the determination of the antenna concept proposed. The Cassegrain type of system has been chosen since it provides the lowest noise temperature consistent with the gain requirement. In addition, a solid rather than mesh reflector has been chosen to avoid noise contributions from leakage through the mesh.

In order to achieve low noise temperatures, the sidelobes and backlobes must be kept very small. The far sidelobes (at large angles from the main axis) are lower with the Cassegrain system than is the case with the feed at the focus of the paraboloid. In the latter case, spillover occurs and is of large enough magnitude to cause significant far sidelobes and consequent increases of noise temperature since these sidelobes point at the earth, a potent source of thermal noise. The Cassegrain type system does tend to have larger sidelobes near the axis because of blocking by the minor reflector and spillover from the feed. Methods for reducing the near-axis sidelobes will be investigated during the Phase I study if the need exists.

A third type of antenna system considered, but rejected, is an array of smaller size antennas. Such a system introduces serious problems in connection with the feeds. The feed lines will be long (and consequently lossy) because of the large size of the array. Noise temperatures would thus be large and loss in the transmitting system large. An alternative is to place separate transmitter output stages and maser amplifiers at each antenna, but then serious difficulties arise in maintaining the critical phase relationships between these amplifiers.

a. Antenna Used as a Receiver

During the Phase I study, the cost of the antenna system as a function of the communications capability will be considered. For purposes of illustrating the parameters to be considered and their relative magnitudes, an antenna with a diameter of 270 feet is used in this proposal.

In order to achieve a large signal to noise ratio for a fixed radiation intensity incident on the antenna, the effective area of the antenna should be large and the effective noise temperature of the receiving system should be small. The figure of merit defined in JPL Engineering Planning Document No. 5 as the ratio of antenna effective area to system noise temperature appears to be a good measure of receiving capability. The dependence of figure of merit on area and temperature is illustrated in Figure III-A-1. The figure shows that if the target specification of 10° K. for the average excess noise temperature of the antenna is achieved and if the temperature due to feed line and reflector losses can be kept down to 5° K, adding to a total temperature of 20° K (including 5° K maser temperature), the effective area of the antenna must be 17,000 sq.ft. to achieve a 12 db increase in performance over the reference value. However, if these temperatures are not achieved and an additional 20° K is added, the antenna must have an effective area of about 34,000 square feet for a 12 db increase in performance. It is shown later that to achieve a 12 db increase in transmitting gain, the effective area must be 43,500 square feet, which corresponds to a 13 db increase in figure of merit for a total temperature of 40° K.

Antenna effective area is proportional to the transverse (projected) physical area of the paraboloid reflector. Several factors contribute to make the effective area less than the physical area. The equation is as follows:

$$A_e = \eta F A \exp\left[-(4\pi\bar{\varepsilon}/\lambda)^2\right]$$

where A_e = antenna effective area for the polarization of the feed
η = aperture efficiency (without considering deflection or phase errors)
F = factor to account for "systematic" deflections such as dead weight and wind loads
A = aperture physical area
$\bar{\varepsilon}$ = rms error of microwave path length due to "random" deflection, such as fabrication tolerances and temperature gradients
λ = wavelength, 5.15 inches for receiving (2295 Mc/s)

The aperture efficiency factor is a function of the amplitude distribution over the aperture, which is the same as the field strength distribution when the antenna is used for transmitting.

FIGURE OF MERIT
VS
ANTENNA EFFECTIVE AREA

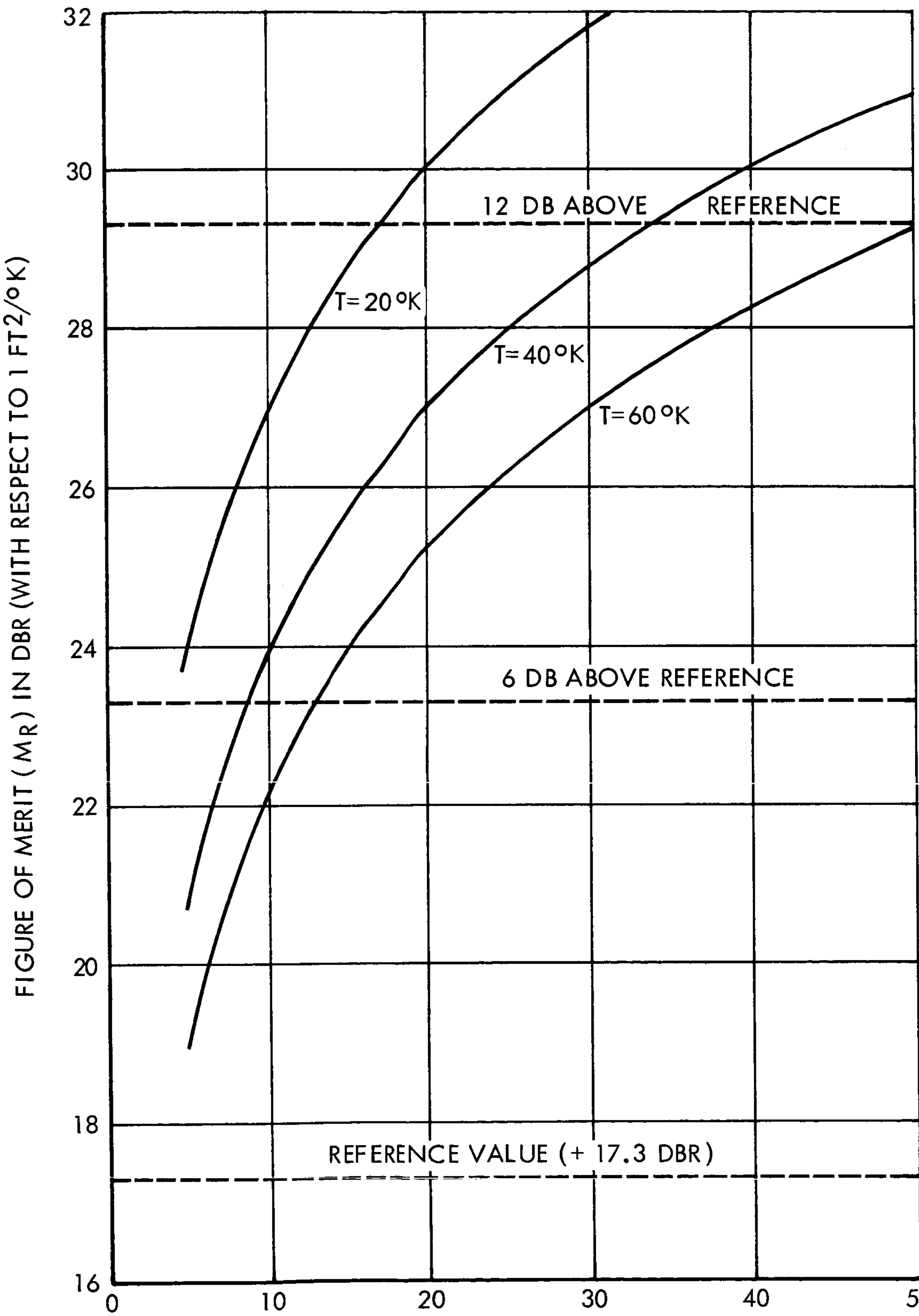


FIGURE III A-1

There are four factors which contribute to making the aperture efficiency less than unity: (1) the taper of illumination at the edges used for the purpose of creating low sidelobes, (2) blocking of radiation in the central region by the minor reflector in the Cassegrain system, (3) spillover from the feed, and (4) ohmic losses. The aperture efficiency factor is relatively independent of the size of the antenna, dependent only on the distribution. For a distribution of the form $(1 - r^2)$, where $\underline{r}$ is the relative radial distance equalling unity at the outer edge, the efficiency factor is 0.75. A Cassegrain system with a 270 foot diameter paraboloid and a 30 foot diameter hyperboloid has an additional factor due to blocking equal to 0.988. Thus, the overall aperture efficiency with a 10 percent reduction due to feed spillover and a 2 percent reduction to account for ohmic losses is 0.725. Although some other distribution will be used, such as a Taylor distribution, this value is adequate for illustrative purposes. The method of calculating the factor due to aperture illumination is shown in Appendix E.

Systematic deflection factor, $\underline{F}$, is a more complicated factor. It is dependent on the positioning of the antenna and the direction and strength of the wind, and it is a function of the size of the antenna. The dependence on wind could be eliminated by using a radome over the whole antenna; however, this is out of the question because of the large contribution to noise temperature caused by the losses of a radome. The deflections due to wind loads cause less system degradation than would a radome. Systematic deflections cause a uniformly varying phase error across the aperture. When the phase error tends to be asymmetrical about the center in any plane through the antenna axis, the effect is to shift the beam off axis. When it is even, or symmetrical about the center, degradation in gain and increase of sidelobe levels result.

It is shown in Appendix F that the average value of $\underline{F}$ is a function of antenna diameter as illustrated in Figure III-A-2. The assumption is made here that the average deflections occurring as a function of antenna position and wind direction and velocity are one-half those occurring for a 30 mile-per-hour wind directed along the axis of the antenna.

The exponential factor due to manufacturing tolerances and thermal effects is very small, contributing less than 0.012 db loss in gain for antenna diameters less than 300 feet. In this case the maximum random deflections expected as a function of antenna diameter are taken to correspond to the $3\bar{e}$ values of microwave path length errors. Contributions from

REDUCTION IN ANTENNA EFFECTIVE AREA
DUE TO DEFLECTIONS VS ANTENNA DIAMETER

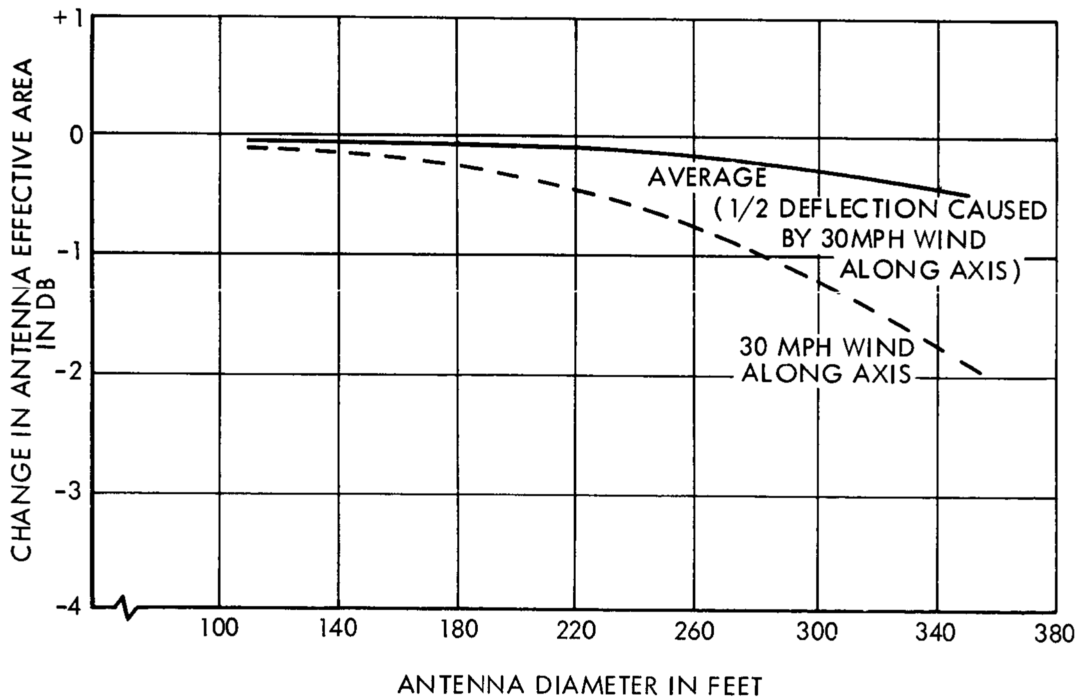


FIGURE III A-2

both the paraboloid and hyperboloid reflectors are included. The tolerances are tighter on the hyperboloid than on the paraboloid because of the magnification effect, i.e., a given deflection in a portion of the hyperboloid surface produces greater error than the same deflection in a portion of the paraboloid surface.

The composite effect of all these factors is illustrated in Figure III-A-3, which shows the effective area of the antenna as a function of its diameter. Thus the 270 foot diameter antenna described in this proposal has an effective area of 35,500 square feet. This area corresponds to an increase in figure of merit above the reference value of 15.2 db for a total system noise temperature of 20°K, an increase of 12.2 db for 40° K, and an increase of 10.4 db for 60° K.

The total system noise temperature consists of the sum of three parts, the average excess noise temperature of the antenna, the excess noise temperature due to feed line and reflector losses, and the excess noise temperature of the amplifier system. An additional contribution would be present amounting to more than 30° K if a radome were used. The average excess noise temperature of the antenna is given by the formula,

$$\bar{T}_{ant} = \frac{\int_{\Omega_1} T(\Omega)\, d\Omega}{\int_{\Omega_1} d\Omega}$$

where Ω_1 is the required solid angle coverage. This coverage region is bounded by cones representing declinations of 35° North and 35° South and by the cone for a 10° elevation angle. The total solid angle coverage is thus as follows:

$$\text{Solid angle coverage} = \int_{\Omega_1} d\Omega$$

$$= \int_{-80^\circ = -0.445\pi}^{80^\circ = 0.445\pi} \int_{55^\circ}^{125^\circ} \sin\theta \, d\theta \, d\phi$$

$$= 1.02\pi = 3.20 \text{ steradians}$$

In this calculation, a spherical coordinate system is set up with the polar axis parallel to the Earth's axis of rotation and the $\phi = 0°$ axis is in the vertical plane in the North-South direction but is South of the local zenith by an angle equal to the latitude of the site. A slight correction is necessary in the above value since $\phi = 80°$ does not exactly correspond to a 10° elevation angle in the local coordinate system.

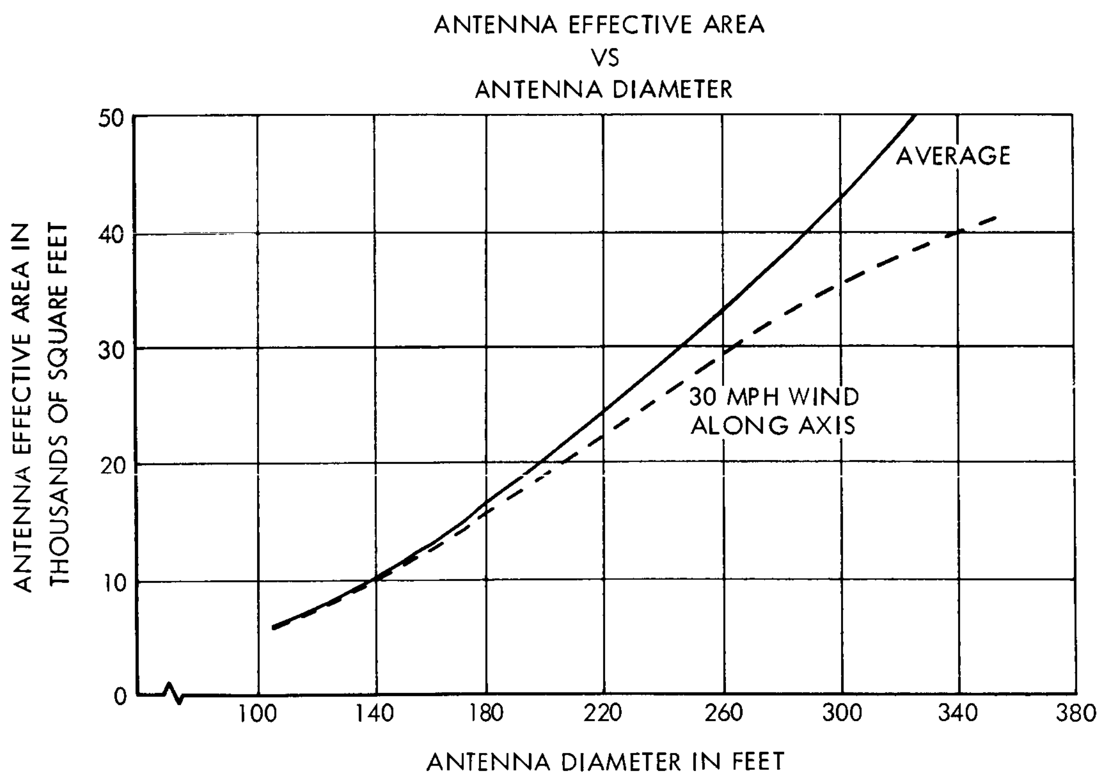


FIGURE III A-3

Average antenna temperature is obtained by calculation of antenna temperature as a function of angle and then integrating over the angular region of interest as indicated in the above equations. At each angle the temperature is dependent on the sidelobe levels of the antenna and the noise sources which each sees. The sidelobes pointing at the ground see a relatively high noise temperature, and the main beam sees a noise temperature due to atmospheric absorption and galactic noise. Added to the ground temperature contribution is a component due to reflected noise from the atmoshpere and space. The overall calculation of average antenna temperature is rather complex if a reasonably accurate value is desired. Therefore, no estimate of expected average antenna temperature is made here. Calculations will be made during the Phase I study program.

It is felt that the target specification value of 10° K for the average antenna temperature will be quite difficult to achieve. The procedure will be to design an antenna with as low sidelobe levels as is possible without the introduction of lossy materials which contribute to noise temperature. The effects on sidelobe level of deflections and manufacturing tolerances will be included in the estimation of these levels. Then should the average antenna temperature which results cause too small a figure of merit, the antenna size will have to be increased. It is expected that the antenna temperature is relatively independent of the size of the antenna.

Design of the antenna for low sidelobe levels will have two objectives, first, low noise temperature, and second sidelobe levels more than 52 db down from the main beam gain at all angles further than 2° from the axis of the main beam. The specification of 52 db down is not impossible since the antenna has a gain of the order of 60 db. Thus the sidelobes are to have a level less than about 8 db above isotropic. The average over all sidelobes must be less than isotropic from the definition of gain. Also, the 52 db specification is met at 2° off axis for an ideal uniformly illuminated aperture, since 2° is several beamwidths off axis. The design of the feed and minor reflector will be such that this specification will be met after taking into account feed spillover, aperture blocking, aperture illumination, deflections, and tolerances.

b. Antenna Used for Transmitting

Transmitting system capability is dependent on the antenna gain. A large a gain as is possible is desired. Gain is directly proportional to antenna effective area according to the following formula:

$$G = \frac{4\pi A_e t}{\lambda^2}$$

where A_e is the effective area as defined previously and t is the transmission factor accounting for feed losses. The effective area for transmitting is slightly different for transmitting than for receiving due to the difference in frequency. For receiving, f = 2295 mc. and λ = 5.15", and for transmitting, f = 2115 mc. and λ = 5.6". When the effective area given previously is corrected for frequency and a transmission factor of 0.975 (loss of 0.1 db) is used, the gain is obtained as a function of antenna diameter as shown in Figure III-A-4. The gain for a 270 foot diameter antenna is 63.0 db, which is 11.1 db above the reference value and 5.1 db above the minimum acceptable value.

c. Position Command Error Sources

Microwave contributions to pointing error consist of deflections of the feed, minor hyperboloid reflector, and major paraboloid reflector. The largest contributions are from deflections of the large reflector due to wind load (when at right angles to the antenna axis) and dead weight (when the antenna is pointing in the horizontal direction). Each of these can cause an error of about 0.01 degree under worst conditions. Besides reducing to a minimum the deflections that occur, the best solution is to program for these predictable errors. Feed and hyperboloid deflections can be kept small enough that they do not contribute significant errors. In order to do this the transverse deflections of the feed and hyperboloid must be less than approximately ± 0.30" and ±0.10", respectively, and the tilt of the hyperboloid less than 0.04 degree.

ANTENNA GAIN
VS
ANTENNA DIAMETER

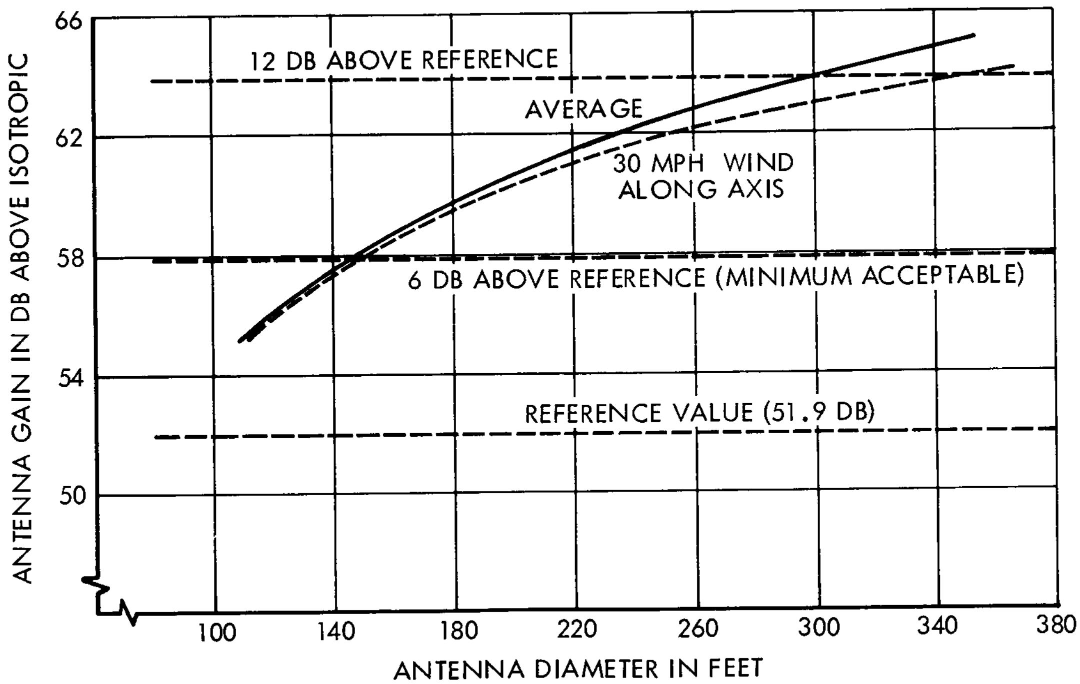


FIGURE III A-4

2. Feed System

Recent advances in the development of low-noise input amplifiers of the Maser or Parametric type have resulted in a complete change in the philosophy of design of low-noise receiving systems. The noise figure of these amplifiers is so low that the overall system noise power is now principally determined by the noise energy delivered to the receiver from the input circuitry; therefore the design of modern high-sensitivity receiving systems must be based upon the reduction of the noise energy of the input circuitry without the degradation of the amplitude and spectral quality of the received signal. Thus the designer is concerned with the maximization of the signal-to-noise ratio in the output of the receiving system.

The following paragraphs describe the parameters which affect the signal-to-noise ratio of the DSIF antenna system and outline studies which should lead to the design of an optimum system. Conclusions as to the basic characteristics of some of the system components are reached in the discussion.

a. The noise power present in the output of the first radio-frequency amplifier may be expressed in terms of three separate components: (a) noise power generated by resistance losses in the surface of the antenna reflector or reflectors, or collected from external noise sources; (b) noise power generated by resistance losses in the primary feed antenna and the transmission line; and (c) noise power generated by the input radio-frequency amplifier over which the system designer may have no control. The equation which defines the total noise power contributed by the above three components is: (Ref. 1)

$$P_n = \frac{GKB}{L}\left[T_a + (L-1)T_t + LT_{er}\right] \qquad (1)$$

where

P_n = noise power present in the amplifier output in watts

G = radio-frequency amplifier power gain ratio

K = Boltzman's constant = 1.37×10^{-23} watts/cps/deg. Kelvin

B = receiving system bandwidth in cycles per second

L = transmission system loss ratio; the ratio of the power delivered into the primary feed antenna (when receiving) to the power delivered into the amplifier input

T_a = effective noise temperature of the receiving antenna in degrees Kelvin
T_t = temperature of the transmission system in degrees Kelvin
T_{er} = effective temperature of the input amplifier in degrees Kelvin.

Equation (1) is defined in such a way that the bracketed terms represent the equivalent noise temperature, T_{eq}, of a single noise source connected to the input of the transmission system; therefore, the ratio G/L represents the equivalent gain of the transmission line-amplifier combination for both the signal and the noise, and only the terms contained in the bracket should be considered when attempting to maximize the system signal-to-noise ratio. For convenience in analysis it is customary to define the total system noise power in terms of the equivalent noise source temperature; therefore equation (1) may be simplified to

$$T_{eq} = T_a + (L-1)T_t + LT_{er}. \qquad (2)$$

(1) The Jet Propulsion Laboratory Engineering Planning Document states that the study of the system total noise is to be restricted to regions involving the following expected parameter values:

$T_{eq} = 20° \text{ K}$

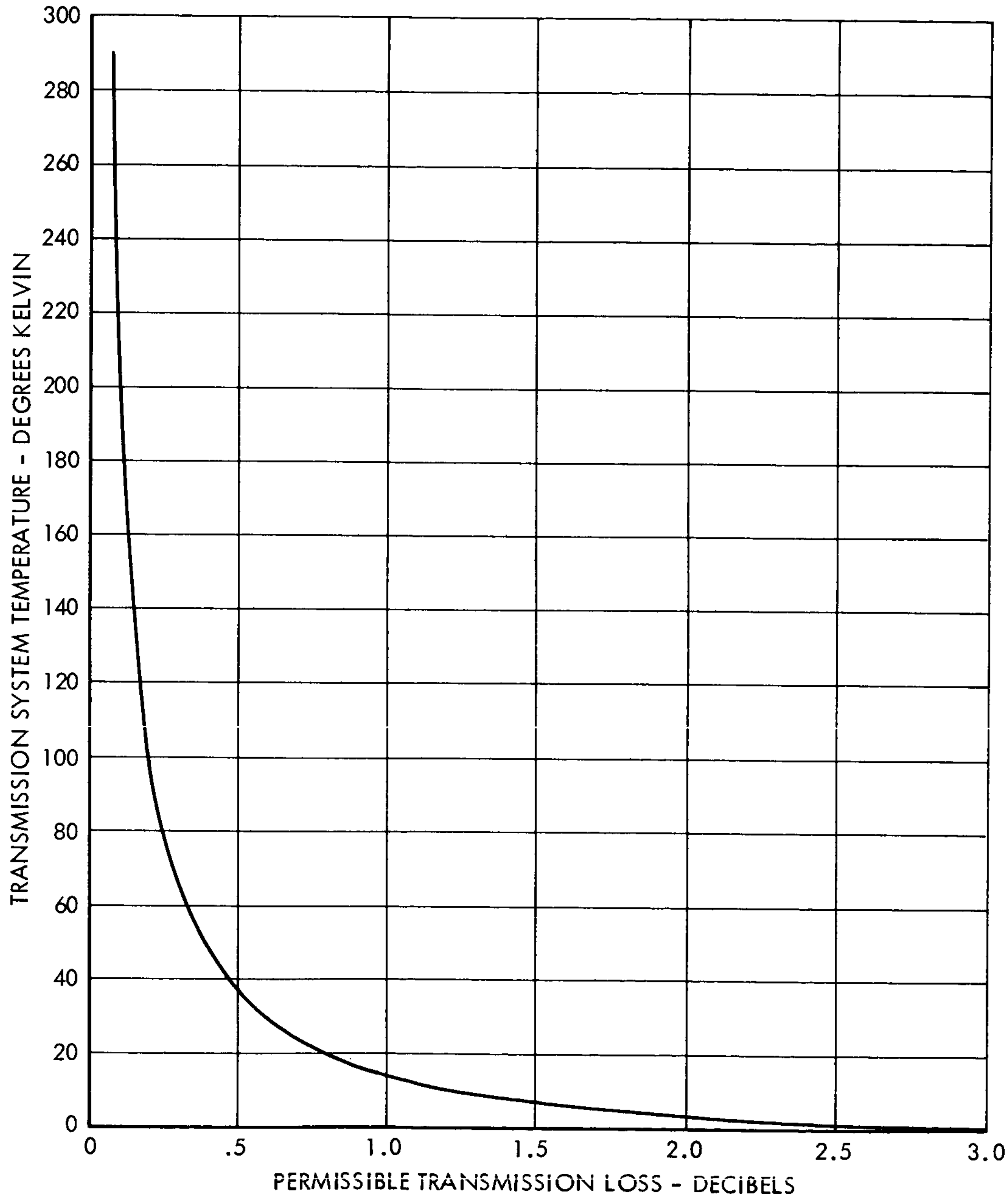
$T_a = 10° \text{ K}$

$T_{er} = 5° \text{ K}$

Solving equation (2) for L and substituting the above values yields:

$$L = \frac{T_t + (T_{eq} - T_a)}{T_t + T_{er}} = \frac{T_t + 10}{T_t + 5}. \qquad (3)$$

Equation (3) defines the permissible transmission loss as a function of the environmental temperature of the transmission system. If the transmission system were immersed in a cooling bath, it is found that the permissible loss is increased, as shown by Figure III-A-5, from a minimum value of .06 - .07 decibels at standard temperature to a maximum theoretical value of three decibels at absolute zero. However, the curve indicates that appreciable reduction of the environmental temperature is required



PERMISSIBLE TRANSMISSION SYSTEM LOSS AS A FUNCTION OF TRANSMISSION SYSTEM ABSOLUTE TEMPERATURE

FIGURE III A-5

before worthwhile increases in permissible system loss are realized. Certainly a cooling bath for a transmission system would be a nuisance to be avoided if at all possible; however if a low-loss transmission system cannot be realized in practice, it may be necessary to consider the use of the cooling bath to achieve the desired overall system noise power level.

It should be noted that the gains achieved by transmission line cooling defined by equation (3) depend strongly upon the actual values obtained for T_a and T_{er}, and therefore the desirability of cooling will depend upon the results of a study to define the temperature of the components of the practical system.

Several conclusions may be reached from the above discussion:

If the transmission system is to operate at standard temperature, it is imperative that losses be held to a minimum. The use of long transmission lines between the feed antenna and the input amplifier, poorly matched couplings or, transition sections, waveguide-to-coaxial transformers, dielectric phase-shifters or antenna loadings, rotating joints, and other producing components is to be avoided.

The length of the transmission system must be held to a minimum, whether cooling is used or not, to reduce loss and complexity. If the antenna were to be used only for receiving, it would be possible to mount the feed antenna at the focal point of a parabolic reflector and to install the radio-frequency amplifier at the output of the feed antenna without complicating the structural design of the feed system; however, if the antenna is to be used for transmitting as well as for receiving, it would be difficult to change feed antennas within the three minute time limit defined by the Engineering Planning Document, and the transmission losses resulting from the long transmission line between the transmitter and the feed antenna would be excessive. These considerations make the Cassegrain antenna system much more attractive compared to the standard parabolic reflector system.

If a Monopulse tracking feed is considered for use in the DSIF antenna system, care must be taken in the design of the input transmission system to achieve accurate tracking and low transmission losses. If the transmission losses become excessive, it may be necessary to cool the input transmission system to meet the figure of merit defined in the Engineering Planning Document.

If a Conical Scan (sequential lobing) tracking system is considered for use in the DSIF tracking mode, it is doubtful that the noise power generated by a spinning or nutating feed may be reduced to the required level. The rotating waveguide joint is inherently noisy, and a nutating system generates noise by mechanical vibration and transmission line flexing.

(2) The noise power delivered into the input of the primary feed antenna is contributed by losses in the large metallic reflectors and by point and distributed noise sources which lie within the field-of-view of the antenna system. It may be shown that the contribution by losses in the metallic reflectors is negligible because of the high surface conductivity and low induced current density; on the other hand, the noise energy collected from point and distributed noise sources may be considerable under certain circumstances. The latter factor must be considered in detail if the effective noise temperature of the antenna is to be accurately estimated and if logical means for the reduction of the noise temperature are to be found. The following factors are considered basic to the problem of calculating the effective antenna noise temperature:

Although the energy radiated from a point source may be spread over a very broad frequency spectrum and almost completely incoherent, the very narrow passband of the DSIF receiver rejects all but a few cycles per second of the source energy spectra. Since the cross-correlation of the residual noise energy is near unity for correlation time delays approaching $1/B$, the noise energy may be considered as coherent and the response of the antenna to the noise energy essentially the same as if the energy were radiated by a coherent source. This would not be true if the system bandwidth were broad (on the order of several megacycles per second), in which case the antenna radiation pattern sidelobes and fine structure at wide angles from the main lobe would be smoothed or leveled, and the response of the antenna to the noise source difficult to define.

If the angular separation of discrete noise sources is several times less than the angular width of the antenna lobe collecting energy from the sources, and if the angular rate-of-change of the intensity of the radiation from the discrete sources is small compared to the width of the antenna lobe, the noise power collected by the antenna lobe may be computed by considering the noise energy as being uniformly distributed in angle and performing a summation weighted by the gain and angular shape of the antenna lobe. On the other hand, if the intensity of the noise energy radiating from the individual noise sources changes appreciably in amplitude within an angle less than the angular width of the antenna lobe, it is necessary to perform two or more separate summations to compute the total noise energy collected by the antenna lobe. For example, if the sun is being viewed by an antenna lobe of angular width less than the angle subtended by the equivalent solar noise source, the angular distribution of noise intensity seen by the antenna lobe may be considered as constant with a relatively high equivalent noise temperature on the order of 3000° K; however, if the antenna lobe is broader in angle than the solar noise source, it is necessary to define the angular portion of the antenna lobe viewing the sun and the portion of the antenna lobe viewing portions of the sky about the sun, and to perform separate summations for the radically different source temperatures.

b. It is appropriate that consideration be given to the effect of the electrical requirements on the geometry of the Cassegrain antenna system, and the drawing of the Cassegrain antenna of Figure III-A-6 may be found useful in the following discussion.

The operation of the Cassegrain system is based upon the optical principle that a source of radiation placed at the focal point of a parabolic reflector may be replaced by a combination of a hyperbolic reflecting surface and source, with the new source of radiation located between the hyperboloic reflectors at a point on the common reflector axes. If the source of radiation is placed at the real focus (F) of the hyperbolic reflector, and the virtual focus (F') of the hyperbolic reflector made to coincide with the focal point of the parabolic reflector, all rays emanating from the source will travel an equal distance to a reference aperture plane and will pass through the plane along paths parallel to the reflector axes. Thus the Cassegrain system produces an in-phase aperture illumination as does the more familiar parabolic reflector system; however, other important differences exist between the two systems.

(1) Figure III-A-6 reveals that a bundle of rays emanating from the true source at F are reflected from the surface of the hyperbolic reflector as if they had originated from a virtual source located at F'. The original ray bundle is shown as emanating from F in a direction θ in respect to the X-axis, but after reflection from the hyperbolic

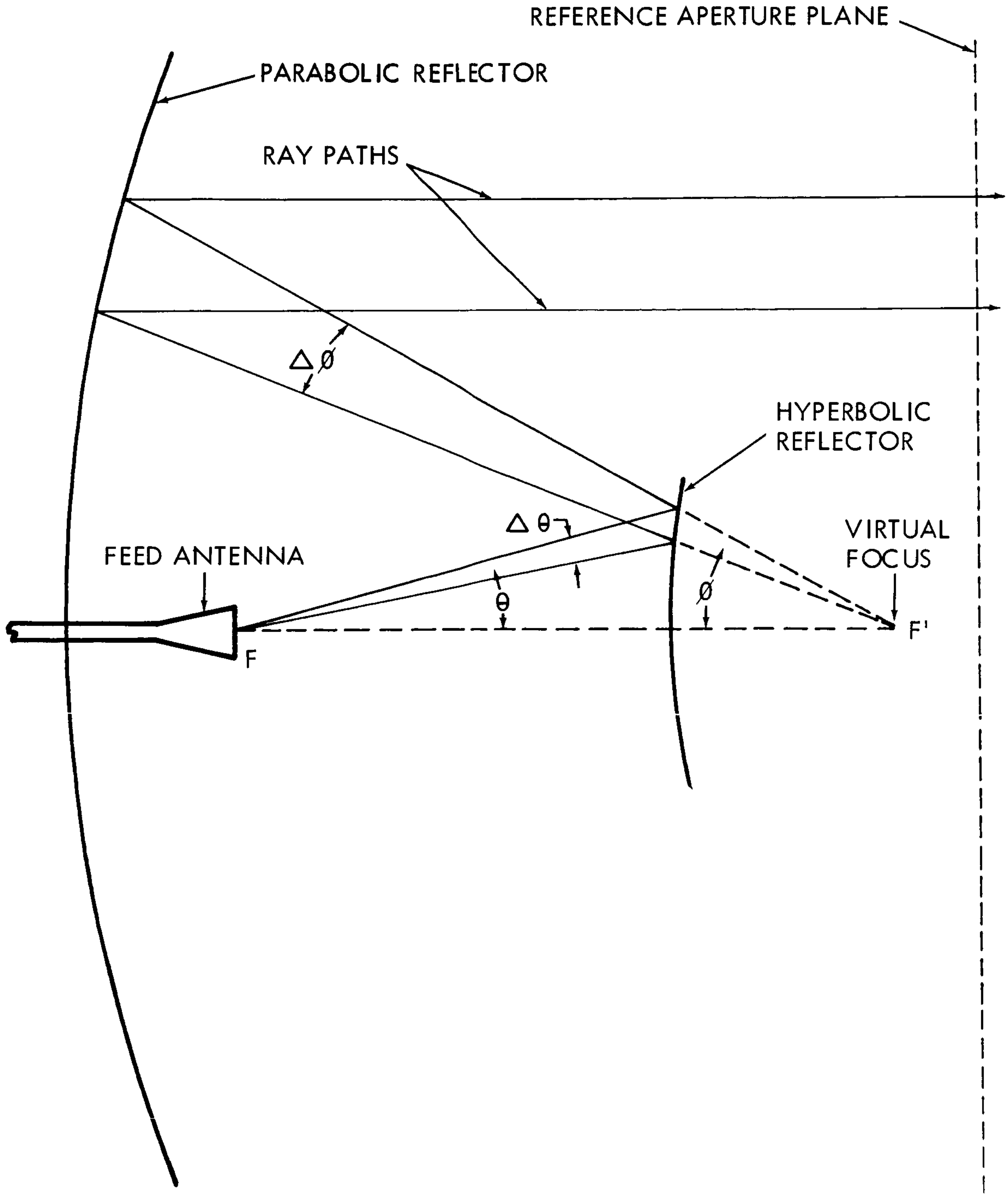


FIGURE III A-6

GEOMETRY OF THE CASSEGRAIN ANTENNA SYSTEM reflector the ray bundle is incident upon the parabolic reflector in a direction ϕ in respect to the X-axis. The result of the change of the direction of the ray path by reflection from the hyperbolic reflector is that the radiation pattern of the virtual source is a function of the radiation pattern of the true source and the transform of the hyperbolic reflector. Two effects may be noted from Figure III-A-6: the radiation pattern of the virtual source is broadened in angle as a function of the ratio ϕ/θ, and the radiation pattern of the virtual source is reduced in angle as a function of the ratio $\Delta\phi/\Delta\theta$ (because ray energy contained within $\Delta\theta$ is distributed over the larger angle $\Delta\phi$ after reflection). Although these two factors oppose each other, they do not cancel; therefore it is possible to use the geometry of the hyperbolic reflector in controlling the distribution of the primary feed energy over the aperture of the parabolic reflector. The rather complicated equation which defines the transfer function relating source radiation pattern to parabolic reflector aperture distribution has been derived; however the study of the equation has not been carried out sufficiently for the presentation of results in this proposal.

An undesirable characteristic of the Cassegrain system is that a discontinuity exists in the amplitude distribution of radio-frequency energy over the antenna aperture because of shadowing by the hyperbolic reflector.

(2) Theoretical and experimental investigations have indicated that tapering of the illumination near the edge of the parabolic reflector will result in a significant reduction of the amplitude of the wide-angle sidelobes. This result is logical in that such tapered illumination implies that essentially all of the energy radiated by the feed antenna is collected by the parabolic reflector, and only a small portion of the energy is permitted to radiate at angles beyond the rim of the reflector to generate undesirable wide-angle sidelobes. It follows that particular attention should be given to the design of the primary feed antenna to obtain a radiation pattern which is low in side and back-lobe content and which will radiate the greatest possible percentage of the total feed antenna power within the conical angle containing the parabolic reflector. The radiation pattern of a typical horn antenna shows that the sidelobe amplitudes are generally greater than the amplitudes of the backlobes; therefore if such a horn is used as a primary feed for a parabolic reflector, the sidelobe energy will radiate in directions

toward the side and rear of the parabolic reflector, and the lower level backlobes will radiate in directions near the parabolic reflector main lobe. Thus the parabolic reflector antenna system tends to have relatively higher sidelobes at and beyond ninety degrees from the main lobe because of imperfect radiation from the primary feed antenna.

If the horn feed antenna is placed at the focal point of a Cassegrain antenna, the situation is reversed; the feed horn sidelobes will now radiate in directions somewhat less than ninety degrees from the Cassegrain antenna main lobe. Again, it is important to pay particular attention in designing the feed antenna so that a very low percentage of the total feed antenna power will radiate beyond the conical angle included by the hyperbolic reflector.

An additional source of undesirable sidelobes in the radiation pattern of the Cassegrain antenna is the discontinuous energy distribution over the reference aperture plane caused by shadows from the hyperbolic reflector and its structural supports. Such aperture blocking results in the generation of higher amplitude sidelobes at angles near the main lobe of the Cassegrain antenna pattern; and an increase in the diameter of the hyperbolic reflector will not only increase the amplitude of these sidelobes, but will also produce additional sidelobes at greater angle s from the main lobe. A previous discussion has indicated that high-level sidelobes at angles near the main lobe will contribute greatly to the noise temperature of the antenna when the main lobe is oriented at low elevation angles; therefore it is of paramount importance that the diameter of the hyperbolic reflector be held to a minimum to reduce the amplitude of these sidelobes. Reduction of the diameter of the hyperbolic reflector may be achieved by reducing the beamwidth of the primary feed antenna radiation pattern and by placing the feed antenna closer to the hyperbolic reflector; however, a narrow beamwidth is achieved only by increasing the aperture of the feed antenna, which in turn extends the far-field boundary of the feed antenna. Thus the minimum diameter of the hyperbolic reflector depends upon the amount of interaction between the feed antenna and the hyperbolic reflector which, if too great, may result in distortion of the parabolic reflector illumination and the generation of undesirable sidelobes.

Tapered aperture distribution functions have been derived by Taylor (Ref. 2) for the reduction of the amplitude of the low order sidelobes. Some of these aperture distributions are most difficult to realize with an ordinary parabolic antenna system because control of the aperture illumination is limited to the ability of the designer to achieve the proper primary feed radiation pattern. However, these distributions should be more easily obtained with Cassegrain antenna because of the additional control available in the choice of the hyperbolic reflector geometry. Even though the Cassegrain antenna aperture distribution is discontinuous because of aperture blocking effects, the Superposition Theorem indicates that the use of a Taylor's distribution will result in a corresponding reduction in low-order sidelobe amplitude.

(3) A final source of undersirable side-lobes is that of structural imperfections in the antenna system which result in deviations in the amplitude and phase distribution of radio-frequency energy over the antenna aperture. Actually such deviation in aperture amplitude and phase distribution are more detrimental to the main lobe peak gain than in the generation of undesirable sidelobes; however, since system performance is based upon signal-to-noise ratio, such deviations in aperture distribution must be minimized. The principal sources of error are:

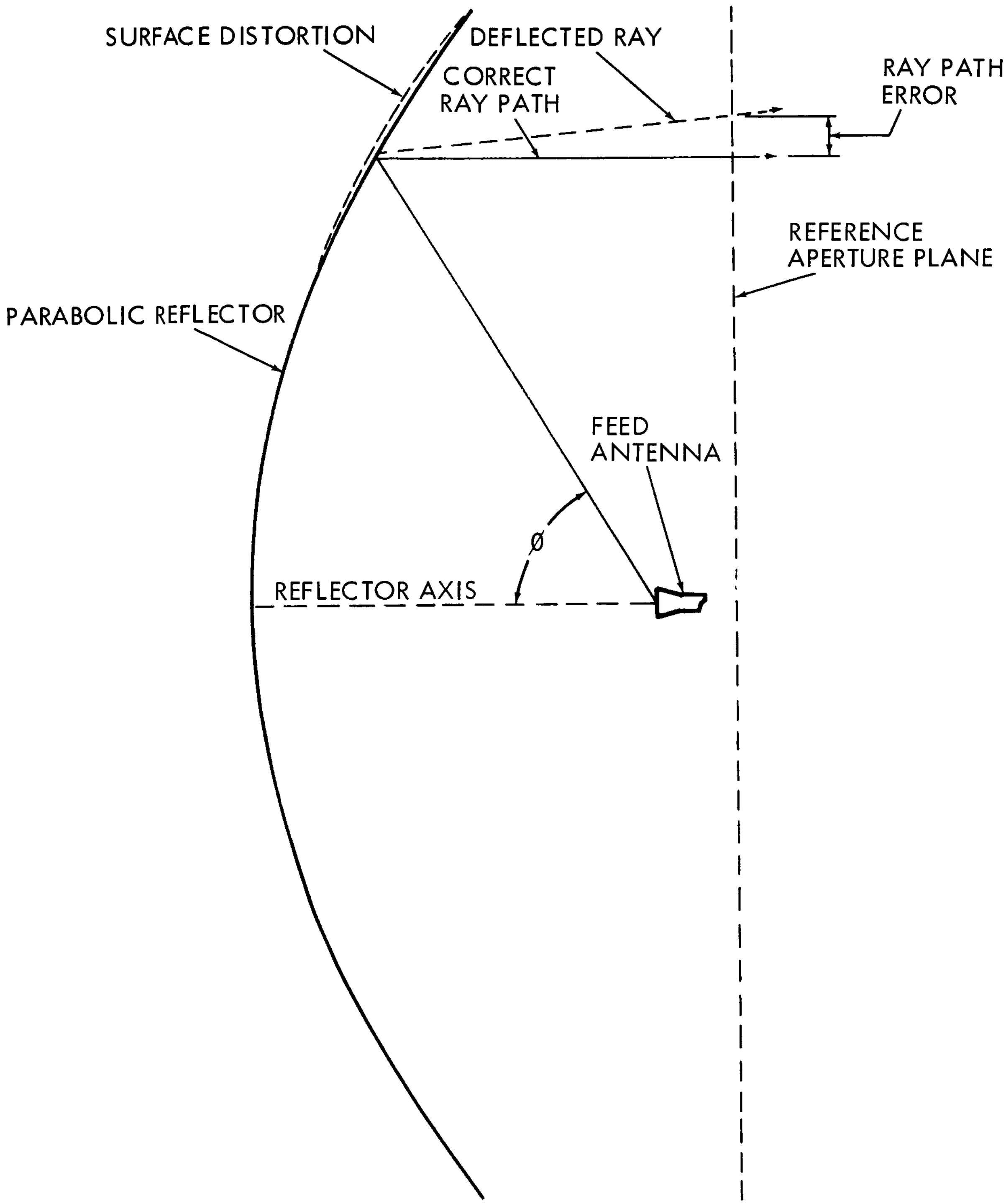
Astigmatism in the Feed Antenna - A characteristic of a linearly polarized horn antenna is that the E-plane and H-plane phase centers are displaced from one another. This displacement of phase-centers results in a distortion of the phase front of the energy radiated from the antenna so that equi-phase contours are no longer purely spherical. It is not possible to locate such an antenna exactly at the antenna focal point, and a distorted aperture phase distribution will result. The effects of such defocusing may be reduced by increasing the focal length of the parabolic reflector; however, the tolerances on the rigidity of the feed horn support structure then become more stringent.

In the case of the Cassegrain antenna system, the effects of feed horn astigmatism may not be pronounced since the virtual focal point lies at a point in space beyond the hyperbolic reflector to provide an effective long focal length. On the other hand, the magnification of the hyperbolic reflector may tend to at least partially counteract the effect of the long virtual focal length. Circularly polarized antennas are to be used in the DSIF antenna system; and the astigmatism of such antennas, if carefully designed and constructed, is relatively small.

It is interesting to note that the phase front of an electromagnetic wave radiated from a source at a low elevation angle above the horizon becomes oftentimes badly distorted by passage through the atmosphere. Such distortion of the wavefront from planar produces the same effect in the antenna as is produced by distortions in the reflector surface; a reduction in main lobe gain and the generation of undesirable side-lobes. Researchers in the field of tropospheric scatter communications have performed experimental measurements to determine the extent of such wavefront distortion on system signal-to-noise ratio as a function of antenna diameter, operating wavelength, elevation angle, and other parameters. Such data should be studied to define the degradation which should be expected for the DSIF antenna system.

Distortions in the Surface of the Reflectors - If the path of an individual ray is traced from the antenna focal point to the parabolic reflector surface and out to the aperture reference plane (as shown in Figure IIIA-7), it may be seen that a distortion of the reflector will produce two effects: the ray path length out to the reference aperture plane will be increased or decreased because of the physical displacement of the reflector surface, and the ray will travel along a path not quite parallel to the antenna axis because of the error in slope of the reflector at the point of ray reflection. It is noted that an additional phase delay is introduced because of the slightly longer ray path length, and that the ray passes through the reference aperture plane at a point displaced from the proper intersection point. Thus the length of the ray path from the point of reflection to the aperture reference plane is of critical importance since the displacement of the ray at the reference aperture plane is proportional to the product of the reflector slope error and the length of the ray path.

A similar ray tracing for the Cassegrain antenna is shown in Figure IIIA-8. The ray leaves the source, is reflected from the hyperbolic reflector to the parabolic reflector, and then out to the reference aperture plane.



DEFLECTION OF A RAY BY A DISTORTED PORTION
OF A PARABOLIC REFLECTOR SURFACE
FIGURE III A-7

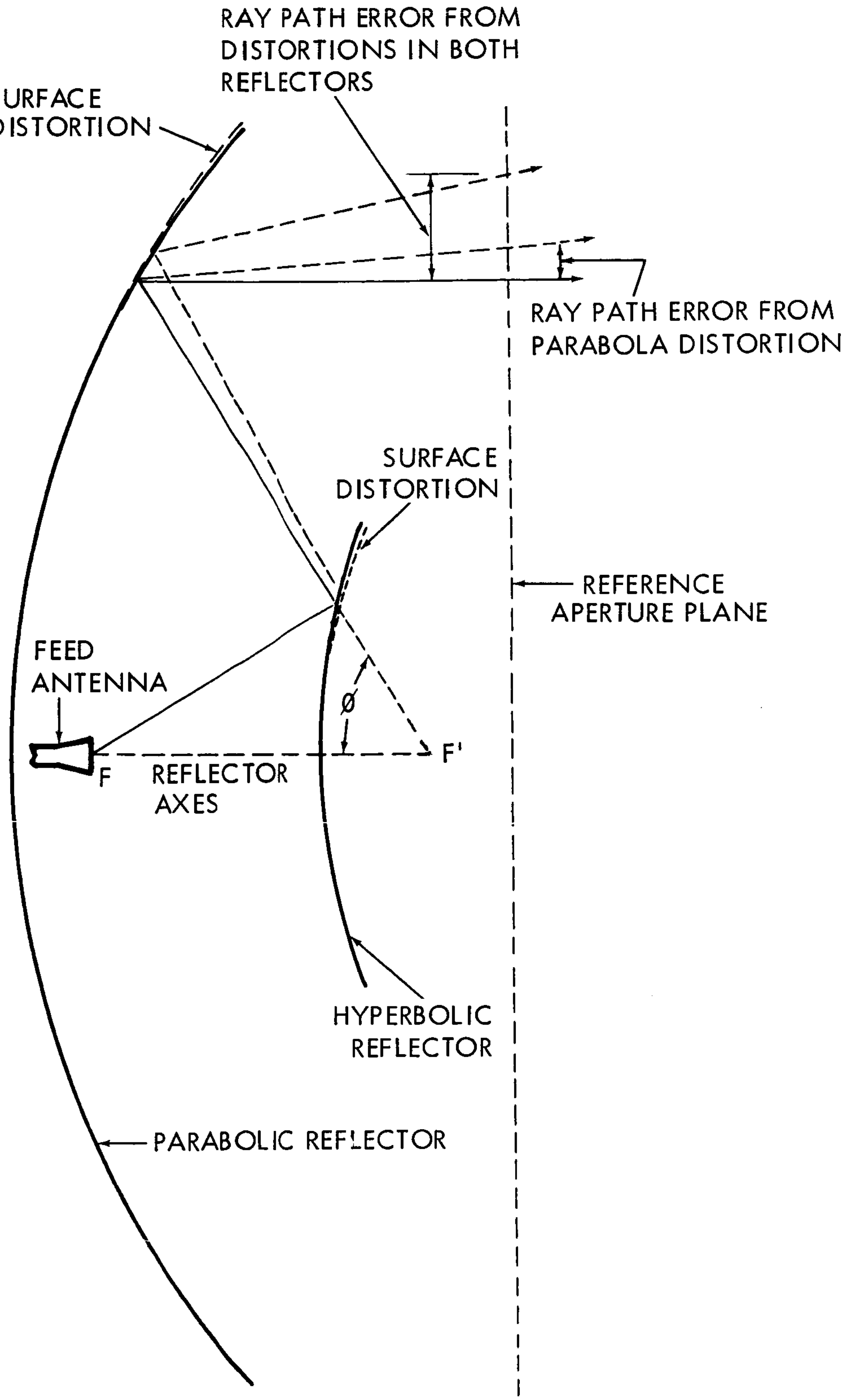


FIGURE III A-8 DEFLECTION OF A RAY BY DISTORTIONS IN THE REFLECTORS OF THE CASSEGRAIN ANTENNA SYSTEM

The path length and position error of the ray at the reference aperture plane is now dependent upon the magnitude and sign of the position and slope errors of both the hyperbolic and parabolic reflectors and, more importantly, upon the path lengths from the hyperbolic and parabolic reflectors to the reference aperture plane. If the ray path length from the hyperbolic reflector to the parabolic reflector is great, an error in the slope of the hyperbolic reflector at the point of ray reflection will cause the ray to be incident upon the parabolic reflector at a point far removed from the correct position. The slope of the parabolic reflector at the actual point of ray reflection is not correct for the direction of arrival of the ray; therefore the ray will be reflected along a path which is not parallel to the antenna axis, and a rather appreciable error in ray position occurs at the reference aperture plane. Thus the structural tolerance of the hyperbolic reflector must be very stringent, particularly near the rim of the reflector where the ray paths to the parabolic reflector are greatest. It is believed that a theoretical study will indicate that the structural tolerance on the hyperbolic reflector must be several times more severe than for the parabolic reflector.

A preliminary study of the structural tolerance requirements for the hyperbolic reflector indicates that the tolerances may be variable as a function of the radial position of the hyperbolic surface from the antenna axis; that is, the surface tolerance requirement is a function of the reflector-to-reflector ray path length for all possible ray paths over the antenna aperture. Thus if a short focal-length antenna system is to be used, the short path lengths for the ray paths near the center will permit the relaxation of the tolerances on the central portion of the hyperbolic reflector, but will require tighter tolerances for the outer portion of the hyperbolic reflector where the ray path lengths are great. Conversely, a long focal length system will result in more nearly uniform reflector-to-reflector ray path lengths, and the radial distribution of structural tolerance on the surface of the hyperbolic reflector may be relatively constant. It may well be that structural considerations may indicate a desirability for a certain type of radial distribution of structural tolerance on the hyperbolic reflector to realize an optimum performance of the complete antenna system.

c. Problems Inherent in the Design of a High-Performance Tracking System.

A preliminary study of the sequential and simultaneous lobing tracking systems has led to the conclusion that a lower feed system noise temperature and much greater tracking accuracy may be achieved with simultaneous lobing. An additional detailed study is required to assure that this conclusion is valid; however, for the present it is assumed that simultaneous lobing is to be used for the tracking mode of operation of the DSIF antenna system. The design of such a system must result from a study of the several problem areas.

(1) Simultaneous (or Monopulse) lobing for tracking is achieved by generating four separate main antenna lobes which are slightly displaced and symmetrically located about a central axis, and by suitable processing of the signals received by the separate antenna beams to provide directional error voltages used to steer the antenna and track the signal source. If the simultaneous lobing is to be mechanized by the excitation of a single reflector by four feed antennas whose phase centers are slightly displaced radially from the reflector focal point, the resulting system is an amplitude monopulse system (phase monopulse requires that the spacing between the feed antennas be comparable to the diameter of the reflector, which is impossible for a single-reflector monopulse system). Each of the lobes generated by the individual feed antennas is "squinted" or inclined at an angle in respect to the reflector boresight axis, and the degree of squint is dependent upon the physical displacement of the feed antenna phase center from the reflector focus and on the focal length of the reflector. For both the standard parabolic reflector and the Cassegrain systems the direction of main lobe squint is opposite the direction of displacement of the feed antenna phase center.

The displacement of the feed antenna phase center from the focus of the reflector system results in an essentially uniform phase but asymmetrical amplitude distribution of radio-frequency energy over the aperture of the parabolic reflector. This results in the generation of somewhat higher amplitude wide-angle side-lobes in the antenna radiation pattern in a direction opposite to the main lobe squint, and in the reduction of the amplitude of the wide-angle side-lobes in the direction of the main lobe squint. Since the noise contributed from the wide-angle side-lobes is the integral of the contributions of all of the wide-angle side-lobes, it is reasonable to assume that the total noise contributed by the wide-angle side-lobes will remain relatively unchanged.

One potential problem exists in that the rotation or squinting of the main lobe and its associated low-order side-lobes may result in a summing of the side-lobes in the combined sum and difference monopulse radiation patterns. If the squint angle were chosen so that the troublesome low-order side-lobes would differ in phase by 180 degrees in respect to each other when combined in the sum channel, a significant reduction of the low-order side-lobes would result. However when combining the radiation in the difference channel it would be found that the individual side-lobes would be in-phase and the resultant difference channel radiation pattern would contain higher amplitude low-order side-lobes. It is more important to reduce the amplitude of the low-order side-lobes in the difference channel radiation pattern, therefore the squint angle should be chosen so that the higher amplitude low-order side-lobes of the individual feed radiation patterns will be of the proper phase to provide cancellation in the difference channel.

The angular sensitivity which is defined as the product of the on-axis sum voltage and the derivative with respect to bearing angle of the received difference voltage is dependent upon the feed horn aperture and f/d ratio of the major reflector. The feed horn-hyperboloid combination values will accurately be determined during Phase I program so that the angular sensitivity will meet the requirements specified.

System accuracy and angular sensitivity are also a function of null depth. To achieve the required null depth, the duplexer will be designed so that the differential phase shift between the colinear arms of the hybrid tee will be less than two degrees. (Ref. 12)

In considering the signal-to-noise ratio developed in the output of the difference channel, one is tempted to conclude that the noise energy collected by the antenna is subtracted out (since the noise energy may be considered coherent) and the resultant signal-to-noise ratio is primarily dependent upon the noise generated by the transmission system. However, such is not the case. The noise energy collected by the antenna is distributed in angle-of-arrival so that the phase of the noise energy as seen by the feed antennas and the difference channel network is a function of the direction of arrival of the noise energy. A computation of the total antenna noise power present after subtraction in the difference channel would demonstrate that little or no reduction of antenna noise power has resulted from the subtraction process, and that the signal-to-noise ratio in the output of the difference channel is dependent still upon both antenna noise and transmission system noise.

(2) A more complex transmission system is required for a monopulse feed to generate the sum and difference signals required for angle tracking and to enable duplexing for alternate transmission and reception. Since the DSIF antenna system is not required to transmit during the tracking mode of operation, some of the duplexing circuitry may be removed to simplify the transmission system. The remaining network is still rather complex, since the network must generate very accurately the combined sum and the orthogonal plane difference signals to achieve accurate tracking. The designer must be concerned with the noise power generated by the insertion loss introduced by the hybrid couplers which generate the sum and difference signals. If such noise power is excessive, then it will be necessary to immerse the network in a cooling bath to reduce the noise power.

d. Conclusions

(1) The importance of minimizing transmission system losses makes the Cassegrain antenna system most attractive; however, even with the short transmission line lengths available with this system, the excessive losses of the monopulse tracking circuitry may make it necessary to use a cooling bath to reduce the transmission system noise temperature to reasonable values.

(2) The design of the feed antennas and transmission lines should be such that all unnecessary bends, couplings, transitions (such as waveguide-to-coaxial transformers), and other loss-producing elements are eliminated. The use of dielectric materials for phase-shifters or antenna loadings is prohibited.

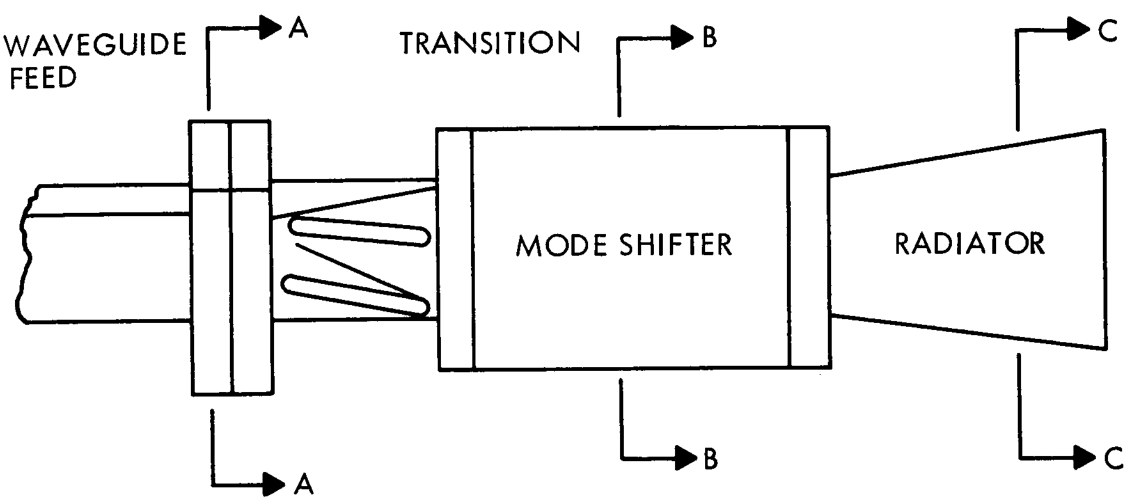
(3) The feed antennas must be designed to reduce side and back-lobe radiation to a minimum, and to deliver the greatest possible percentage of the radiated energy within the conical angle included by the hyperbolic and parabolic reflectors to minimize side-lobes produced by escaping feed antenna radiation. The usual coaxially-fed dielectric-loaded circularly polarized antenna cannot be used in this application because of noise generated by dielectric loss and excessive loss produced by the coaxial-to-waveguide transformer; therefore the feed antenna should be of the direct-coupled waveguide horn type depicted in Figures IIIA-9 and IIIA-10.

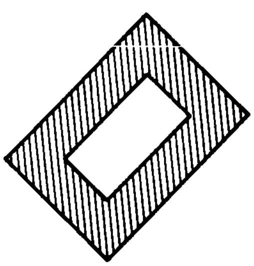
(4) The wide-angle side-lobes of the Cassegrain antenna system appear to be of an amplitude sufficiently low to consider them a relatively minor source of antenna noise. On the other hand, the low-order side-lobes near the antenna main beam may contribute significant noise power when the antenna is operated at low elevation angles. The amplitude of these side-lobes may be reduced by minimizing aperture blocking and by the use of special tapered aperture distributions that have been mathematically derived for this purpose. The geometry of the Cassegrain system is such that the special aperture distributions should be more easily achieved by control of the shape of the feed antenna radiation pattern and by proper choice of the hyperbolic reflector geometry.

(5) The structural tolerances for the hyperbolic reflector are more severe than for the parabolic reflector. The radial distribution of the structural tolerance appears to be a function of the effective focal length-to-diameter ratio for the Cassegrain antenna; therefore a coordinated study of structural and electrical requirements should lead to the design of an optimum system.

(6) The amplitude monopulse tracking system appears to be most desirable from the standpoints of minimum effective antenna noise temperature and lowest achievable aperture blocking by the hyperbolic reflector. Careful design will be required to achieve the performance figure of merit defined by the JPL Engineering Planning Document.

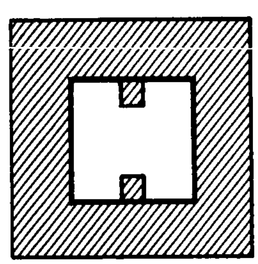
TWO RIDGED CIRCULARLY POLARIZED HORN ANTENNA



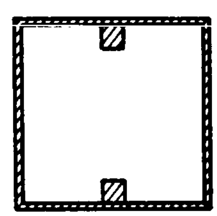


SECTION A-A

NORMAL POSITION 45° TO TRANSITION-RIGHT OR LEFT HAND CP CAN BE ACCOMPLISHED BY ROTATING SECTION A-A 90° FROM NORMAL



SECTION B-B



SECTION C-C

FIGURE III A-9

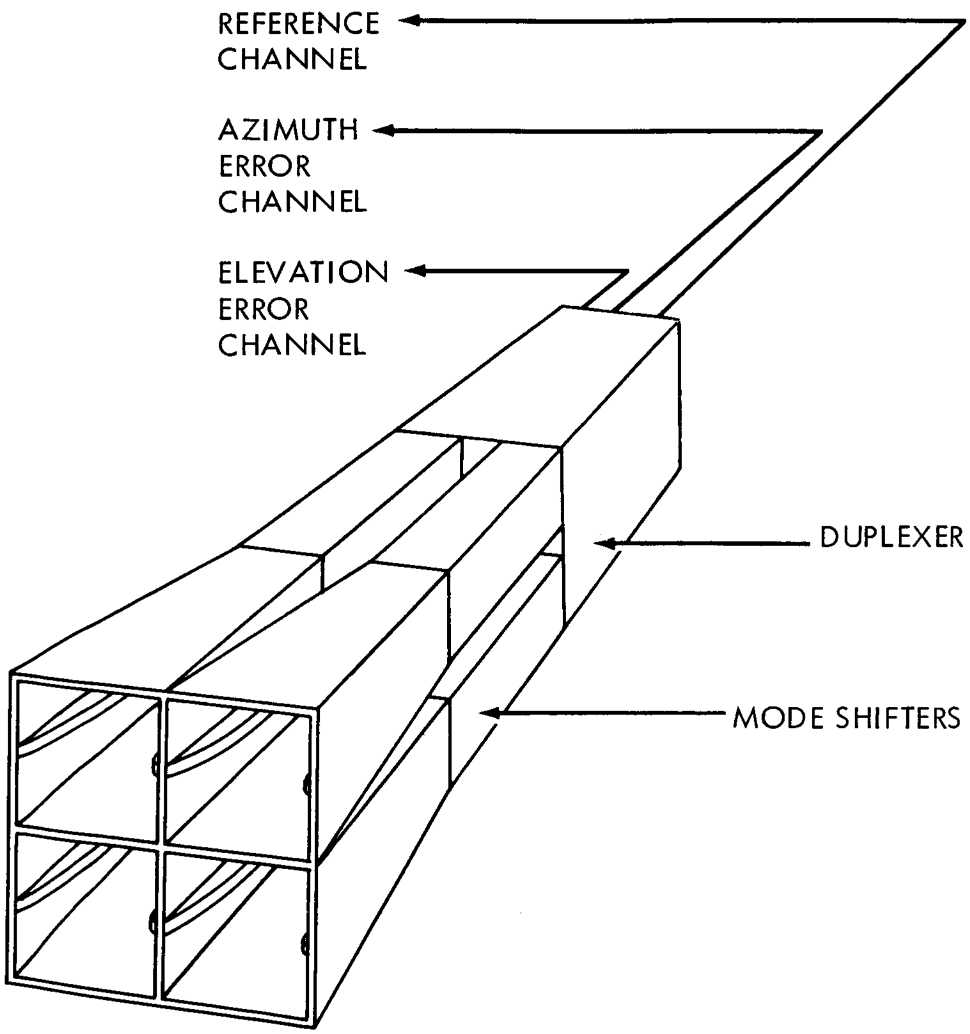


FIGURE III A-10

FOUR HORN CIRCULAR POLARIZED FEED SYSTEM
FOR SIMULTANEOUS LOBING

3. Boresighting and Checkout System

Design of the checkout system is based on optical instruments conventionally used in accurate angular measuring techniques. The selection of an optical system to perform checkout functions is made after considering its inherent capabilities such as extreme accuracy, reliability, simplicity of operation and moderate cost.

a. Static Checking

The following discussion pertains to the technique and procedure for static checking of surface deflections and positional accuracy of both the primary and secondary reflectors in all pointing attitudes. The technique will be also used in the rigging and erection of the antenna system.

During erection of the antenna, the rf axis of the reflectors is permanently established by installation of an alignment telescope rigidly attached to the support structure. An instrument mount is established on the front of the feed horn mount structure. An instrument consisting of two displaced penta prisms, each having a set of optical wedges of predetermined angular design, is optically aligned on this mount. Predetermined points, defining the parabola, are located on the surface of the primary reflector and consist of machine bolts, seated in bushed holes, with graduated and illuminated optical targets seated in each bolt. Adjustment of the bolt adjusts the particular panel surface. A line of sight when rotated through 360° would scribe a reference circle on a perfect paraboloid. Deviation of the primary reflector surface from the perfect paraboloid would then be directly measured by displacement of the instrument cross hairs on the graduated optical targets. The procedure would be repeated with the displaced penta prism optical system. All points on the remaining reference circles are measured and adjusted in similar mode. Positional accuracy of the secondary reflector, in three planes, is determined by autocollimation and triangulation. Surface accuracy is determined by the same technique used with the primary reflector in that the same instrument and its fixed location is used. Only the objective prism is replaced with a system specifically designed for the secondary surface profile determination.

b. Boresighting Techniques

To achieve maximum efficiency of the DSIF antenna and tracking capability, collimation towers will be utilized to accurately determine the RF and optical axis.

The basic reference of the antenna will be the optical boresight telescope which will be mounted in the antenna aperture structure as shown in Figure IIIA-11 and will serve as the alignment reference of the antenna. Dynamic tests utilizing optics will be performed to assure that the relationship between the boresight optical axis and the antenna mechanical axis will be maintained to $\pm.005^{\circ}$ or better for all aspects of the antenna. This will be accomplished by the Alignment Telescope at the hyperbola viewing four illuminated targets that define the r.f. plane and simultaneously viewing the target through the boresight telescope. Both telescopes are an integral optical and structural entity.

The initial static optical alignment of the antenna will be performed as stated in paragraph a. of this section.

The next tests will be performed by positioning the antenna toward a predetermined target on the collimating towers and noting whether the optical alignment of the antenna remains constant.

The inputs to the TV camera mounted in the hyperboloid Fig. IIIA-12 will be received via a prism so as to pick up the target on the collimating tower, and reference points on the third ring of the parabolic reflector. This technique will insure that a constant relationship exists between the paraboloidal and hyperboloidal surfaces.

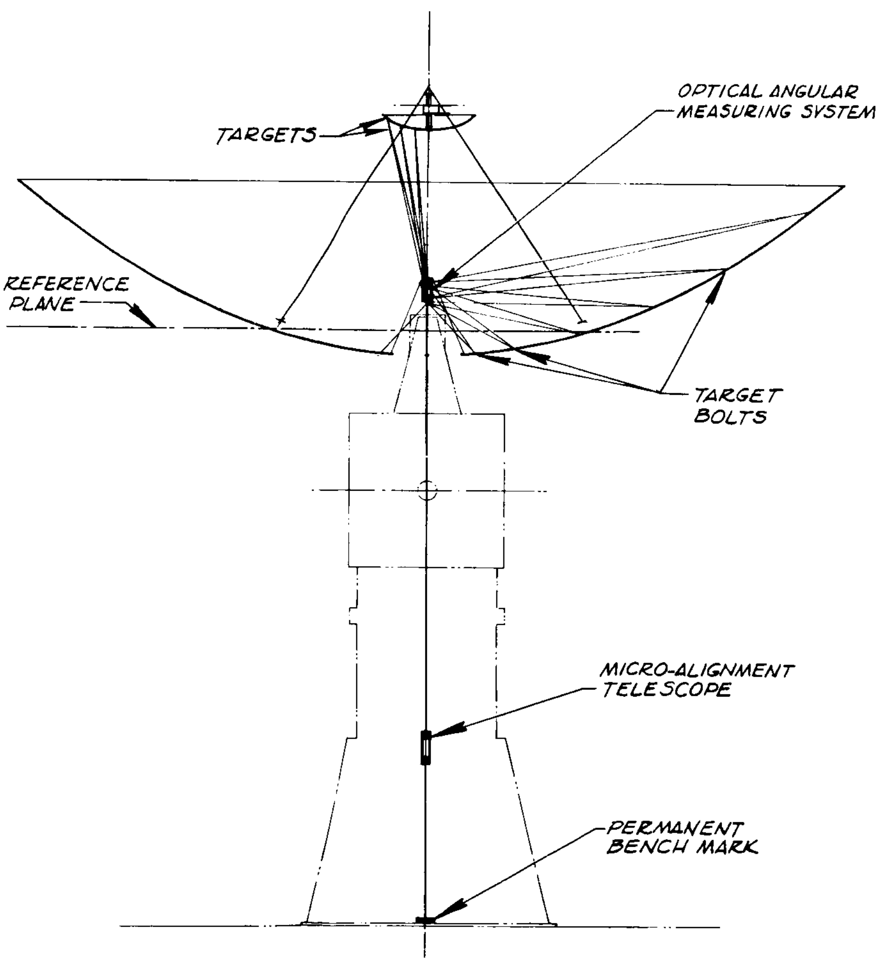
Upon successful completion of these optical tests, the RF feed assembly will be installed and aligned such that the RF axis will be broughtinto parallelism with the optical axis.

c. Collimating Tower Instrumentation

The collimation towers height, distance from the DSIF antenna and antenna parameters will be investigated accurately during Phase 1. The factors that must be determined are:

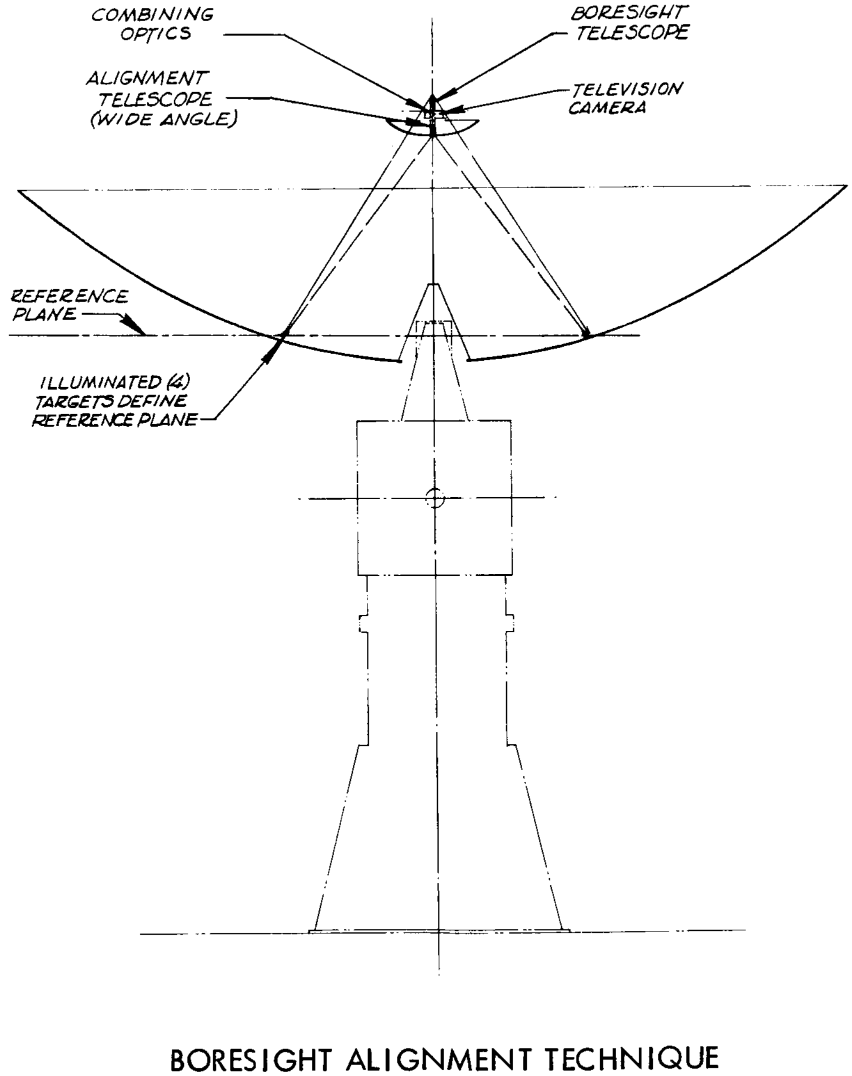
(a) DSIF antenna field distribution in the vicinity of the collimation towers. This information will be derived from the field distribution across the antenna aperture.
(b) Optimum site location to minimize ground reflection.
(c) Site accessibility, etc.

Due to the large size of the antenna, it will be necessary to perform measurements in the pseudo far field; however, this situation will not affect RF alignment because of axial



STATIC OPTICAL ALIGNMENT SYSTEM

FIGURE III A-11



BORESIGHT ALIGNMENT TECHNIQUE

FIGURE III A-12

symmetry of the fields. A comparison technique will be used to investigate the antenna lobe structure.

The mechanical system on the collimation towers will consist of three antennas mounted on a carriage which can travel on rollers or remain fixed. The sensor system as shown in Figure IIIA-13 is a three-antenna array with probing antennas displaced so that they subtend the half power beamwidth angle of the test antenna. The center antenna will be used as a reference for the optical system alignment and monitor of the main lobe maximum point.

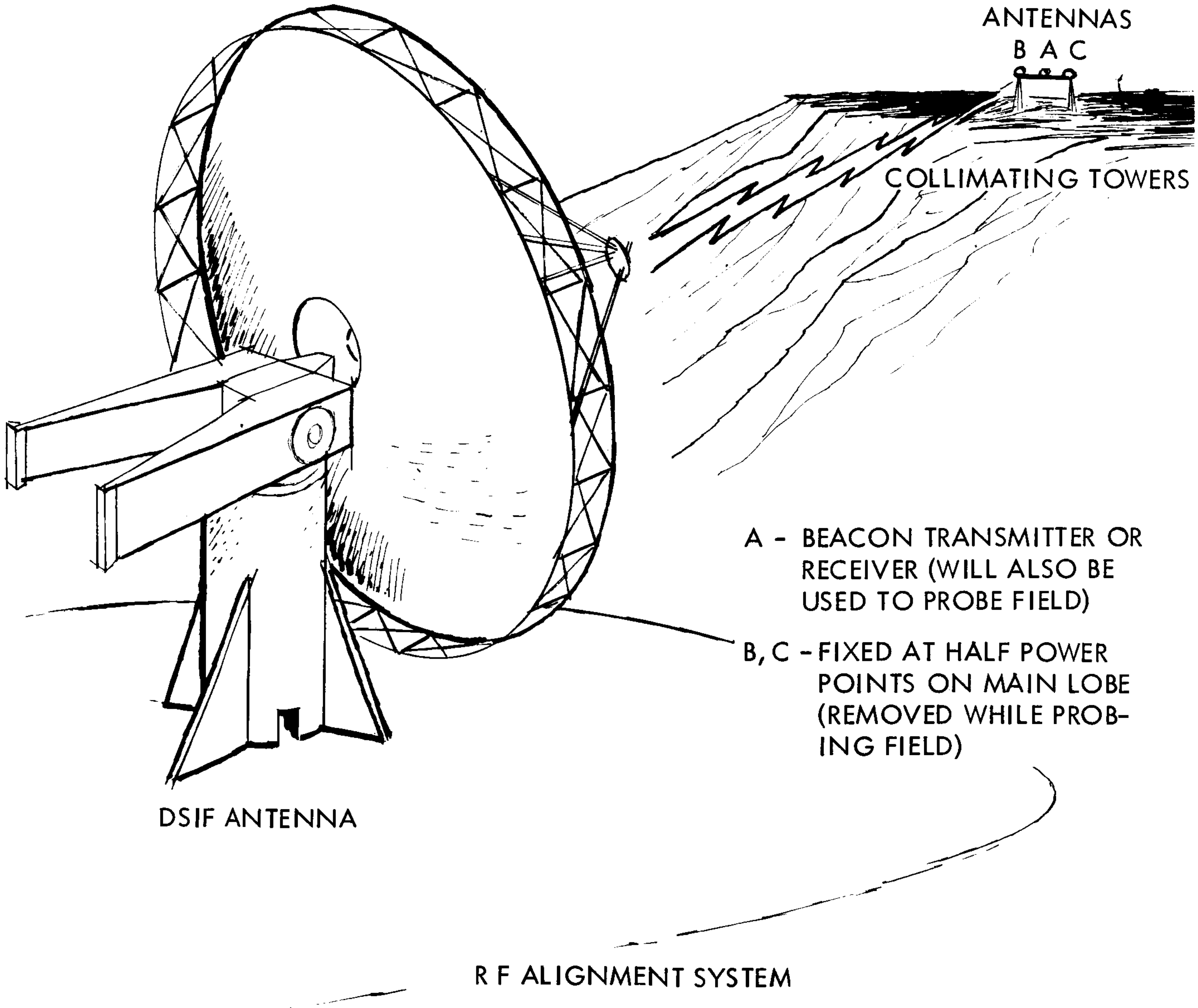
One advantage of the three antenna system over the single collimation tower is that the pattern shape can be determined by using a single pick up antenna and probing the field between the half power points. This technique will assure that reflection from surrounding areas will not affect the true RF alignment. Another advantage is that an increase in accuracy of RF alignment can be obtained by positioning the antennas at the half power points which is a curve described by a negative second derivative.

d. Alignment Technique for S Band Transmitter Feed, Listening Feed and Tracking Feed.

Alignment of the S band transmitting and receiving feeds will be accomplished by utilizing the DSIF antenna as a transmitter and the antennas on the collimation towers as receivers. Since the two antennas and associated microwave plumbing will be matched previously, the video output will be compared and a nulling indicator will determine when the RF axis and optical axis produce parallelism.

The R.F. Tracking feed and duplexer combination will be tested separately to insure proper field distribution across the apertures and alignment of the horn cluster before mounting in the DSIF antenna.

Alignment and calibration of the DSIF antenna during the tracking mode will be accomplished by mounting a low power transmitting source to the center antenna on the collimation tower and using the DSIF antenna as a receiver. Detectors will be connected to the reference and error channels of the duplexer to determine alignment accuracy by recording depth of null, magnitude and linearity of slopes adjacent to the null.



A - BEACON TRANSMITTER OR RECEIVER (WILL ALSO BE USED TO PROBE FIELD)

B, C - FIXED AT HALF POWER POINTS ON MAIN LOBE (REMOVED WHILE PROBING FIELD)

R F ALIGNMENT SYSTEM

FIGURE III A-13

e. Calibration of Systematic Error

To calibrate the systematic error that might occur in the antenna structure and the readout components for various aspects of the antenna, the reference telescope and T.V. camera will be utilized to track optical stars whose position and path are known.

The antenna pointing direction, readout system, and star position will be compared to determine if the magnitude of systematic error is within specification requirements. The R.F. system will be used simultaneously to insure parallelism of the optical and R.F. axis by employing radiometry techniques in the receiver.

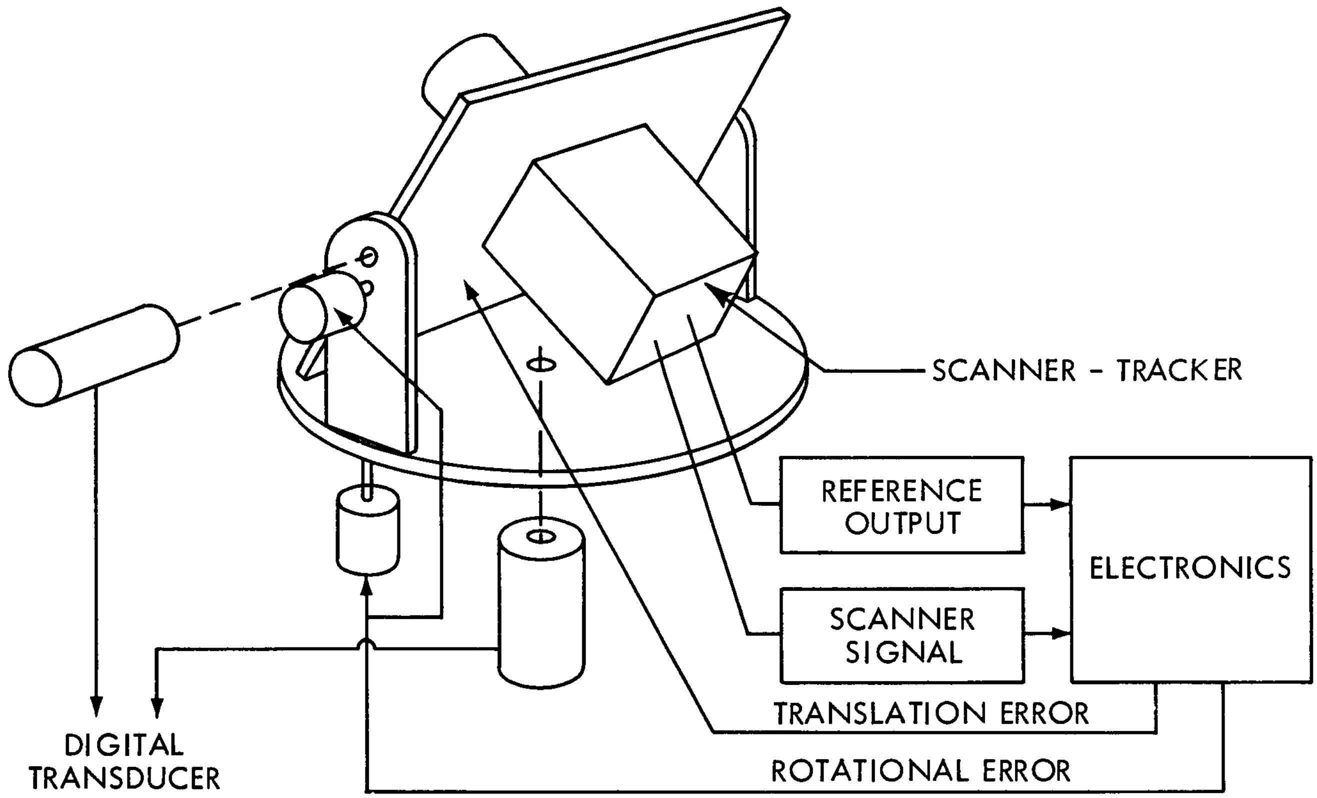
4. Controls and Programming System

a. Position Read-out

The fundamental concept of the positional read-out system is to by-pass as much as possible structure which might introduce deflectional errors. At this stage of the investigation, and subject to Phase I study, it is recommended that the positional read-out be an optical device. The basic measurement is made by the "scanning-tracking" unit mounted on the pylon. This massive pylon will be extremely stable and referred to the local geodetic coordinate system. At the same time, an azimuth reference would be established.

As stated in Sec. III-A-3, the parallelism of the rf and optical axis is not changed due to changes in antenna attitude. However, the displacement or rotation of the antenna axis referenced to the pylon axis because of wind loading, thermal stresses, dead weight loading, etc., is not negligible nor completely predictable, and would cause significant pointing errors if the positional read-out transducer were fixed to the azimuth and elevation axes of the mount. Additional error would be introduced by inertial wind-up, bearing runout and alignment errors.

The scanning and tracking unit, Figure IIIA-14, has four degrees of freedom, two translational and two rotational. The translation loop is to insure that the extended antenna optical or rf axis is always coincident with the measuring optical axis. The amount of excursion of the unit will be determined during the Phase I program.



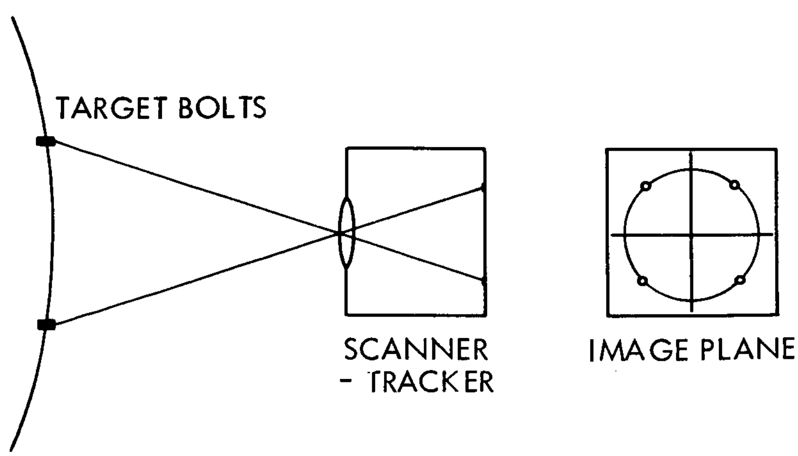


FIGURE III A-14
FUNCTIONAL DIAGRAM OF SCANNING & TRACKING UNIT

As shown in Figure IIIA-14, the translation unit is mounted on the platform of the rotational unit. The positional pickoff transducers are mounted so that the tracking line of sight to the antenna reference is a measure of the antenna axis (azimuth and elevation angles).

The recommended shaft to digital converter would be equivalent to the Norden digital "microgoniometers". These devices have the inherent accuracy (3.6 sec), range (360,000 counts per turn), resolution (0.001 degree) required to meet the DSIF requirements. The type of coding used will be determined during the Phase I program (based on compatibility with other subsystems and efficiency). The display described in para. b. of this section will be an additional factor in the system specification.

The error signals of the scanning-tracking unit will be derived in the scanner unit electronics. The functional optical system is shown in Figure IIIA-14. The image of the target bolts is projected on the scanning surface. A sequential sampling of each image with reference to the optical axis is made. The combined motion of the images will determine the type of error, whether translation or rotation, and the direction of this error. During Phase I, the sensitivity, loop gain, velocity constant of the tracking servo systems must be investigated to establish high static and dynamic accuracy.

If during the course of Phase I, or Phase II, it is found that the stiffness of the structure is inadequate, or other unforeseen deflections occur, an additional scanning system would be used. This system would be similar to the one described above and would insure the parallelism of the optical and rf axes by servo control of the hyperboloidal reflector position. The equipment would be a modification of the boresight TV camera providing a view of the "target bolts", and furnishing signals similar to those from the positional readout equipment. From this data the reference plane of the hyperboloid would be maintained parallel to the four reference targets.

b. Antenna Axis Digital Readouts and Display Devices

The antenna pointing angles (azimuth and elevation) will be displayed at the servo control console. The display is a inline decimal display utilizing the "Nixie" tubes or equivalent. The electronics to drive the "Nixie" display is part of the "Microgoniometer" equipment. This equipment has a resolution of 0.001 degrees. Other types of displays are available, and during Phase I a study program will be followed to optimize the display of all such data.

The display of the SHA and declination axis read-out will require the mechanization of the conversion formulas relating the two coordinate systems. This mechanization is an analog converter using the same digital shaft encoder and read-out display as in the azimuth-elevation display.

The equipment used in the azimuth-elevation display will supply a digital azimuth/elevation output. This output is in binary coded decimal, BCD, suitable for recording and transmission, matched to the JPL equipment.

c. Command Position Error Signal Generation

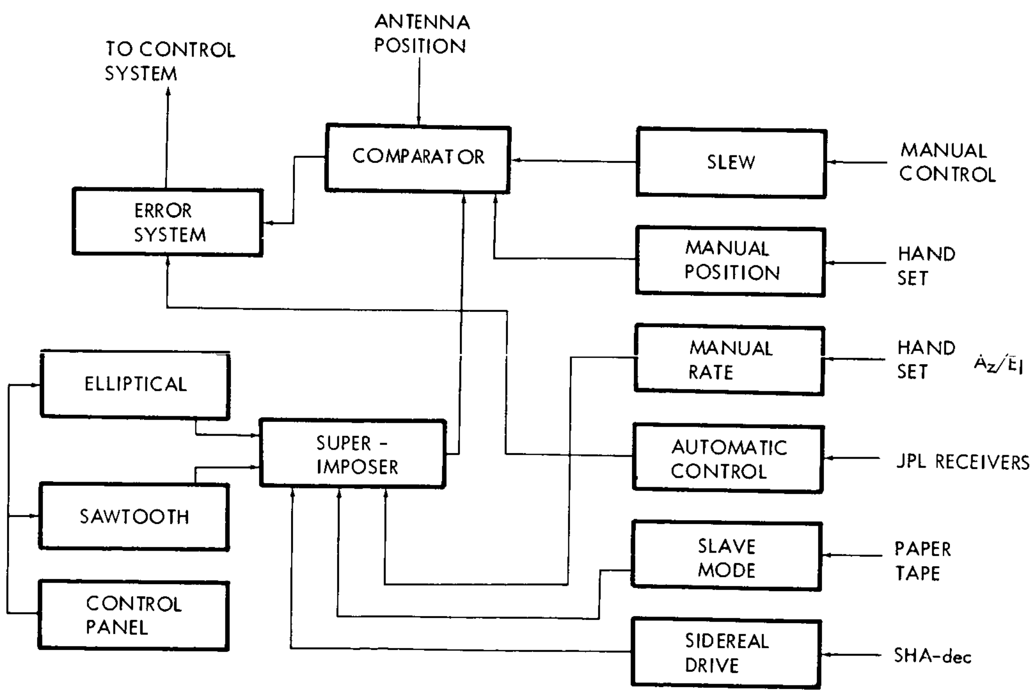
The operating modes of the DSIF antenna system are shown in Figure IIIA-15. Six different modes are provided; slew, manual position and rate, automatic track, slave and sidereal drive. A second set of operational modes (scanning) is described in the next section. In general, this is a positional servo system obtaining the error feedback signal from the comparison of measured antenna position and desired position. During Phase I an investigation of techniques, i.e., digital, analog or a hybrid of the two, must be conducted to obtain a reliable, accurate and compatible overall data system approach.

Special attention must be paid to the automatic tracking mode since by nature this is an analog system. The error signal is derived from a lobing system of antenna.

The sidereal drive section will require a SHA/dec conversion to azimuth/elevation similar to that used in the display section. In this manner the same type of signals are used in the generation of the servo error signal.

d. Scan Generator

This equipment is to provide a scanning signal superimposed on the manual rate, sidereal rate or the slave commands, see Figure IIIA-15. As pointed out in the preceding paragraph, the type of control will be dependent on the Phase I study. However, it is recommended that a digital system be used.



OPERATING MODES & SCAN GENERATOR

FIGURE III A-15

The generation of the elliptical and/or sawtooth signal could use digital differential analyzer technique. This would eliminate the need for analog-to-digital conversion if the scanning function were generated by electromechanical means.

B. STRUCTURAL SYSTEM

1. Reflector

Axial load configuration is the selected approach to the structural design of a large diameter precision antenna reflector system. This concept selection is predicated on the theoretical potentials that exist in the configuration. The ultimate in structural efficiency is achieved when 100% of the structure is loaded axially in resisting applied forces, as in the case of a thin spherical shell under internal pressure. Unfortunately, few designs permit this degree of efficiency, and the best which can be achieved is to utilize this principle in strategic parts of the structure where geometry permits. The axial load configuration employs this philosophy wherever practical.

The reflector face consists of annular rows of panels, preloaded in compression by annular tension cables which also establish the face structure as an integral dish. This face is supported by a back-up structure consisting of concentric annular rings, each of which is a regular polyhedron and which is braced by inter-ring and intra-ring axially loaded members. These rings act as beams, the caps of which are axially loaded. The proportions of load carried by the dish and by the back-up structure are optimized to give minimum deflection.

The basic back-up structure is stabilized against side loads, and edge deflections of the basic reflector face are further reduced by a system of near-radial beams composed of axially loaded members. Certain of the inter-ring tension rods are utilized as diagonals for these bays, hence the auxiliary beams follow the best geometry available in the pattern formed by these members when viewed along the RF axis.

Deadweight and wind loads are passed into the back-up structure by attachment fittings such that a specific (main) ring becomes a collection member; four equidistant points on this ring are established as pick-up points which support the reflector system.

A detail enumeration of the antenna structural features and factors contributing to the concept choice follows:

The axial-load design concept for antenna reflectors is the most rigid for a given weight (or lightest for a given stiffness), and, therefore, the most economical of all known designs. Deriving from this are the following additional benefits:

Lightest construction for given stiffness means that deflections due to dead-weight are minimized.

Lightest weight to meet the specifications means least cost of material, manufacture, transportation, handling and erection.

The Columbus Division of North American Aviation has studied this method of design for several years and as a result has amassed considerable background data with regard to structural performance effects on electronic performance, structural optimization of major components, overall design considerations and detail design problems and solutions. A method of performance prediction has been established to rapidly study antenna structure, and an IBM structural analysis program established. This program would be executed in-plant by the company's computer facility. From this wealth of data it has been determined that the axial-load design will fulfill the requirements of the JPL specification in overall performance, deflection, natural frequency, and environment.

The natural load paths inherent in this design allow deadweight and environmental loads to enter the supporting substructure in a straightforward manner. The hyperbolic reflector support struts are readily attached to the basic parabolic reflector structure without inducing deflections in this structure. In the case of a large diameter precision antenna, this isolation of load is a significant feature affecting its performance.

A solid reflector face, rather than a mesh surface, is required to meet the electronic requirement of low noise. Therefore, it logically follows that the lightest face structure will be composed of sandwich panels. This method of construction provides the greatest stiffness to weight ratio of those currently in use. This design is also the one most compatible with the axial load concept, in which the face panels of the antenna form a shell which is preloaded by annular tension cables. Further, the axial-load concept permits use of a maximum number of identical face panels, thus contributing to low manufacturing cost. In detail, the reflector face features are:

On a large antenna the panels will be thick enough to permit the use of the lowest cost manufacturing process available.

The face sheet material for the sandwich panels will be inherently resistant to corrosion and weathering or will be suitably protected. All panels will be sealed weathertight.

Adhesive bonding will most probably be used to maintain the lowest manufacturing tolerances. ASTM reports satisfactory weathering characteristics.

In order to eliminate thermal expansion problems due to dissimilar materials the basic back-up structure will be of one structural metal. The only structure that may be different will be in the cables used for preloading the reflector face and for supporting the hyperbolic reflector struts. Thermal expansion problems associated with these cables and other structure have been examined and positive solutions are known.

The Columbus Division of North American Aviation possesses a sound and thorough knowledge of all facets of the above design.

The hyperbolic secondary reflector also employs the axial-load design concept. Since the surface accuracy of this reflector is most critical, a servo operated face may be required to maintain system performance under all conditions of ambient temperature and solar heating. This will be determined during optimizations of the system.

A four-strut suspension for the hyperbolic reflector is used in order to make use of the natural load paths within the primary parabolic reflector and suspension structure. The attachment of the hyperbolic reflector to the struts will provide minimum aperture blockage. Also, the struts will be oriented in respect to the parabolic reflector to minimize aperture blockage of this component.

The minor (hyperbolic) reflector is mounted by four braced struts, which attach to the same four mounting points on the main ring structure of the primary reflector. Use of materials having different thermal expansion coefficients is avoided as much as possible, and where such design is necessary the resultant effects are minimized.

2. Antenna Mount

The elevation-azimuth mount is also of prime importance, and has effects upon the overall antenna system performance which are equal in importance to those effects of the antenna reflector system structure itself. The mount design is also a prime factor in control power; and control system design, cost, and complexity. Effort has, therefore, been expended to determine the best configuration for the elevation-azimuth mount.

The ground rules used in this evaluation were as follows:

To support the antenna reflector system structure at its natural load application points, thereby minimizing system deflections and antenna reflector structure.

To position the equipment room along the RF axis, as close as possible to the parabolic reflector vertex without having any of its loads applied to the reflector structure, and to provide gimballing in elevation of this room such that the floor remains horizontal.

To provide the most rigid structure possible at the lowest cost and weight.

To be simple in construction and require a minimum of close tolerance work in both manufacture and erection.

To keep azimuth and elevation axes coincident.

To direct structural deflections of the system in the manner least detrimental to system performance.

To keep antenna reflector system loads and mount loads segregated insofar as possible and to avoid thermal expansion effects caused by use of materials other than those used in the antenna reflector system.

To provide static balancing, and if possible dynamic balancing, about both elevation and azimuth axes.

To have the capability of plunging (moving in elevation from horizon to horizon).

Five different structural configurations were briefly evaluated to determine the most suitable preliminary arrangement. These are described as Configurations A through E below, and the findings are presented in tabular form Figure IIIB-1 for easy comparison. See Appendix D.

Configuration A.

A mount in which the elevation and azimuth axes are made coincident and the elevation axis is kept as close to the antenna system center of mass as possible, together with use of a large hydrostatic bearing consistent with the present state-of-the-art.

Configuration B.

A mount in which the center of mass is coincident with the elevation axis. This is obtained by supporting the antenna at its periphery upon twin towers. These towers are connected by a beam and mounted upon azimuth drive carriages running on a track. The beam mounts the elevation drive motors at its center and also houses a pintle bearing. The towers are braced to non-driven carriages running on a second track concentric with the first.

Configuration C.

A mount in which coincidence of elevation and azimuth axes and full balancing is sacrificed in order to minimize the elevation-azimuth mount. It was seen that this mount was obviously inferior at a very early stage but it was pursued in order to provide background information. However, this mount permitted a good stowed position.

Configuration D.

A type of suspension in which the trunnion beams, containing bearing plates, are circular arcs. These "wheels" run in hydrostatic saddles which in turn rest upon hydrostatic slipper pads. These latter pads form the azimuth bearing surface. Clamps are provided to lock the wheels to the saddles for survival wind load conditions and the saddles are sufficiently wide to resist overturning action under normal operating wind conditions. The bearing wheels are braced and pretensioned to minimize deflection under load. The saddles are connected by a crossbeam.

Configuration E.

A mount designed to the simplest physical layout, balanced and sized as dictated by the basic antenna system geometry and weight. A 45-foot diameter azimuth bearing is used. The basic elements are a central structural block, having the azimuth bearing on its lower surface and the elevation bearings on its vertical sides. This block rests on top of a concrete tower, and rotates in azimuth only. Two beams run on either side and pick up the elevation bearings. At their forward ends they are cross-braced into one unit and support the equipment room. Twin ballast weights are cantilevered at the other ends of the beams. Four adjustable points are provided on the forward face of the structure to mount the antenna reflector system. Basic dimensions of all the above configurations are included in the tabulation.

From the above appraisals, approach "E" is expected to culminate in an optimum configuration. This design is described in detail below.

3. Detail Description of Elevation-Azimuth Mount

a. Pedestal

The pedestal is an earthquake-resistant concrete tower structure, approximately 120 feet in height. It is firmly founded upon concrete surfacing and footers. At the top of the concrete tower, a steel base is mounted. This base has levelling features and is of sufficient depth and thickness to ensure uniform support of the lower half of the azimuth bearing. Since this bearing is approximately 45 feet in diameter, the tower will be at least 50 feet in diameter at its top. The cross-section of the tower is not a significant detail provided that the tower meets the requirements of rigidity, azimuth bearing support, and clearance of the antenna system.

It is conceivable that the steel bearing support at the top of the tower could be used for drive system components. However, the remainder of the tower may be utilized as follows:

a. equipment storage
b. instrumentation rooms
c. laboratory areas and workshops
d. living quarters
e. water storage

The tower may be square, octagonal, or round.

b. Azimuth and Elevation Bearings Housing

This component rotates in azimuth only and has an envelope of approximately 50 feet on a side. Its lower surface is attached to the top of the azimuth bearing, and the elevation bearings are mounted on its vertical sides. Elevation drive motors and racks are mounted in the structure. The structure may be either a space frame structure of low cost standard structural steel sections, or a plated structure; in either case, the loads carried by the structure will be distributed uniformly to the azimuth bearing. This will be achieved by a shear stress distribution section in the lower portion of the housing.

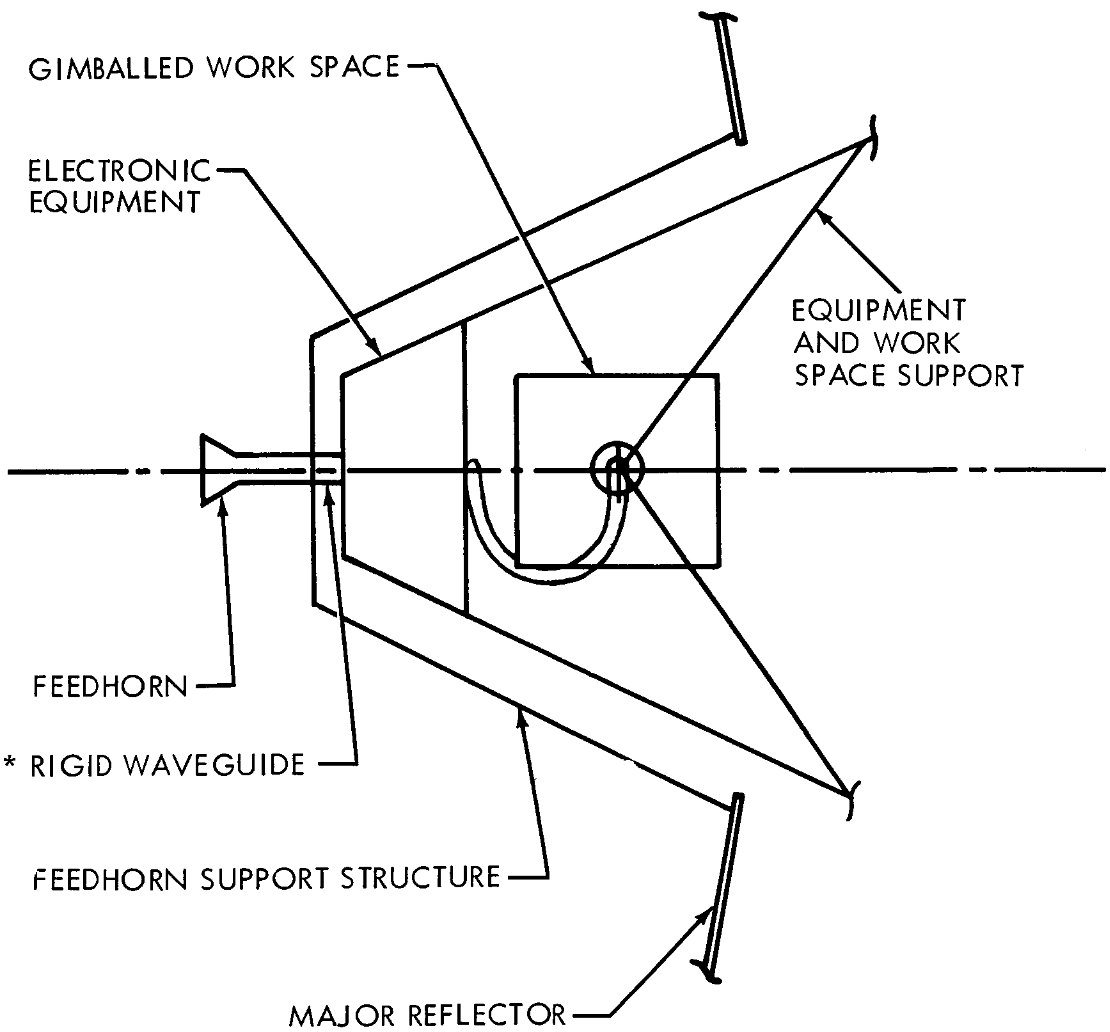
c. Mount Beams

Passing on either side of the azimuth and elevation bearing housing are two main beams. These beams rotate in elevation only relative to the housing, and can accommodate elevation drive motors or racks. The forward ends of these beams extend about 65 feet forward of the elevation axis, and spread into a space structure about 110 feet square at this point. The beams are trussed together by triangulated structure forward of the elevation and azimuth bearing housing such that they form one rigid unit. The working area is gimbal-mounted from the base of the structure supporting the feeds. The RF equipment is installed in an area within the feed-support structure, as shown in Fig. IIIB-2. This allows the equipment weight to be borne by the Mount Beams rather than the reflector, permits short waveguide runs, and requires only power, coolant, and high-level RF cables to be "wrapped up". The aft ends of these beams run about 120 to 130 feet behind the elevation axis as twin cantilevers. These cantilevers pass either side of the pedestal when the antenna system points to the zenith. Twin concrete block counterbalance weights are located at the ends of these cantilevers and give balance about the elevation and azimuth axes. The beams are about 50 feet deep by 30 feet wide at the elevation bearings. They are made of low cost standard structural steel sections with concrete ballast.

d. Basic Mounting Provisions

At the corners of the 110-foot square formed by the beams and their trussing structure are four mounting points which pick up the basic antenna system. These points are coincident with the bases of the four hyperbolic reflector support struts and are at the natural load paths of the system.

If the mount and reflector face are made of different materials, these mounts will be provided with varying degrees of freedom of movement at 90° to the RF axis. When the system is heated or cooled with respect to the basic assembly temperature, differential expansion of the mount and the basic antenna system is absorbed by the movements of the truss connected to these joints. The net effect is a translation with negligible rotation of the basic antenna system axis and the basic mount system axis in the directions shown in Figure 6.



* LONG ENOUGH TO ABSORB MINOR VARIATIONS OF DEFLECTION BETWEEN FEEDHORN SUPPORT STRUCTURE AND EQUIPMENT SUPPORT STRUCTURE.

FIGURE III B-2. ELECTRONIC EQUIPMENT BAY AND GIMBALLED WORK ROOM

e. Deadweight Effect on Mount

When in the zenith position, deadweight loads applied by the basic antenna system are picked up by the four mounting points and transferred to the elevation bearings by the forward beam assembly. This compresses the beam structure axially. As the antenna system rotates toward 0° elevation, the entire basic system moves forward slightly relative to the elevation axis as this compressive load is relieved. This has no effect on system accuracy or performance. The deadweight load becomes reacted by the forward portion of the beams as cantilevers. Due to the proportions of these beam sections (65 feet long by an average of 80 feet deep), almost all deflection caused by the deadweight load comes from the shear members and results in a translation of the RF axis downward with negligible rotation. This has no effect upon the basic system accuracy or performance. Only very slight rotation due to the bending of these cantilevers occurs. If further study shows this to be significant, the truss deflection from deadweight deflection will be measured and programmed out of the pointing data system.

4. Optimization Studies

In completing the design of the antenna structure, during the Phase I program, the following optimization studies will be completed:

a. The number, depth, and cap size of the annular beams within the back-up structure, and the location, depth, and cap size of the main annular beam will be optimized with regard to the total deflection weight and moment of inertia of the basic parabolic reflector face. It will also be necessary to optimize the structural deflection distribution over the reflector face such that the structural deflections are most compatible with the distribution of energy (illumination) over the surface.

b. The number and size of the individual reflector face panels together with face sheet thickness, core design and size and material must be evaluated for shipping, manufacturing, and erecting costs. Stiffness and resistance to corrosion and weathering; and amount of load carried in proportion to the back-up structure must be analyzed. This optimization must also take into account the proportion of preload in the face applied by the annular tension cables.

c. The annular tension cables will be optimized as to number, location, and load in each cable.

d. The number, depth, cap size and location of the auxiliary back-up structural beams will be studied with regard to unsymmetrical loads on the reflector system and their effect on distribution of deflections about the working faces of the structure.

e. Since the hyperbolic reflector currently envisaged (30 to 40 feet in diameter) is large, it justified the use of the same type of structure as the primary reflector. Hence, the same series of optimizations as given in A, B, C, and D will be used for this secondary structure.

f. In view of the fact that the antenna system is exposed to solar radiation, optimization of the manner in which this solar energy is absorbed and reflected by the basic antenna system will be performed. It is proposed that a study of temperature distributions within the structure be made, varying

(1) The reflectivity of the primary and secondary reflector surfaces, by varying the finish of such surfaces.

(2) The convection cooling rate, as by blowing air across the faces of the reflectors (or some similar cooling system).

It is also proposed to examine the use of a servoed hyperbolic face to allow compensation for thermal deflections of the hyperbolic reflector surface.

The results of these studies will be appraised against their effects on the structural performance of the system and the cost and complexity involved in special finishes, cooling systems, servo system, and so on. An optimization analysis of wind load effects and methods to be used to reduce the resultant antenna system performance degradation to a minimum will be conducted in conjunction with optimization of the structural components.

g. Supporting struts carrying the hyperbolic reflector structure will be optimized to minimize deadweight and wind load deflections. The supporting tower for the feedhorn will also be optimized, keeping in mind that the movements of the feedhorn normal to the RF axis are most critical.

The major structural optimization involved is the proportioning of the ballast weight and the associated supporting cantilevers formed by the aft sections of the mount beams. The factors to be appraised are: ballast size, both weight and volume; degree of dynamic balance; and natural frequency of arms.

Further design study will be made of individual member size and location within the elevation-azimuth mount structure; however, this will be mainly detail design.

C. CONTROL SYSTEM

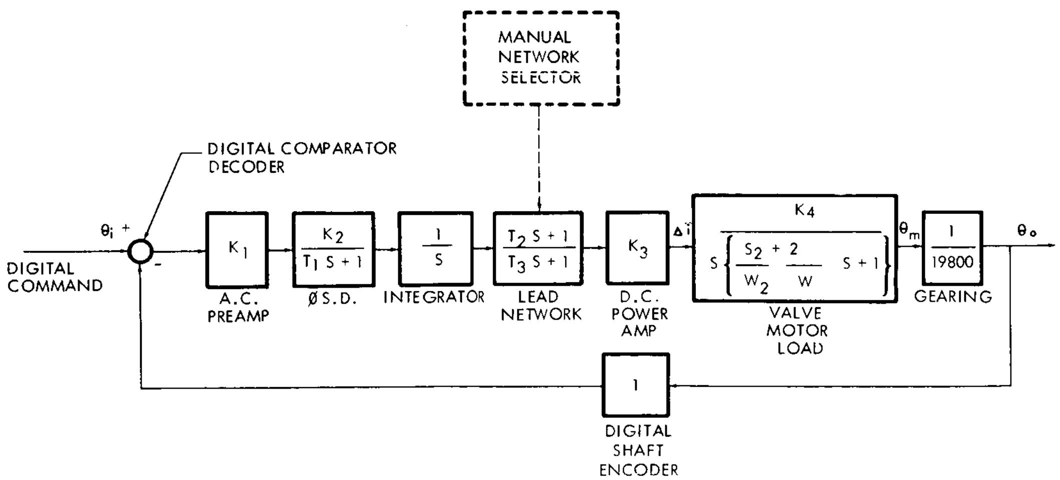
1. Control System Summary

To present some of the problems encountered in meeting the specified requirements of the control system, a hypothetical control system is described. This control system was based on the selected antenna configuration, utilizing an electro-hydraulic drive, gear reductions, and hydrostatic bearings. A detailed design synthesis of this system is covered in Appendix B, together with the reasons for the system selection. It is certainly not to be implied here that the hypothetical system is the only approach, and other methods and configurations will be investigated during the Phase I study. Pursuing this approach, however, was justified in that it exposed problems that can be discussed in specific detail, whereas the problems would not have been as apparent had no system synthesis been attempted. A block diagram of the hypothetical system is shown in Figure III C -1. The specified design goals were considered as mandatory for the hypothetical system although a cost trade-off between meeting minimum requirements and design goals will be developed during the Phase I study.

The major problem area for the servo system is simultaneously meeting the pointing accuracy (high gain) with a very low closed-loop bandwidth. The implications are discussed in the following paragraphs.

2. Servo System

The preliminary servo system synthesis revealed that the most significant problem is simultaneously satisfying the pointing accuracy requirement and the lowest closed-loop bandwidth requirement. While both of these requirements can be met simultaneously on paper, the practical limitation is the large time constants required to maintain high system gain while minimizing bandwidth. If it is required that both high loop gain and .01 cycles per second be accomplished simultaneously, this can be accomplished by either a multimode control system or a deliberately non-linear control system. It is felt that, in view of this sophistication, the exact use of the bandwidth adjustment needs clarification.



HYPOTHETICAL SERVO SYSTEM BLOCK DIAGRAM

FIGURE III C-1

2. Servo System (Continued)

Minimizing the closed-loop bandwidth is important for minimum noise transmission. If the requirement for having the bandwidth adjustable in no less than four steps from 0.01 to 0.2 cycles per second is to be taken simultaneously with the velocity constant implied by the pointing accuracy, a difficult design problem is imposed. The first approach to synthesizing a system to meet the .01 cps bandwidth simultaneously with high pointing accuracy requirements was successful on paper.

A Type I system was designed using velocity feedback through two differentiating networks as a minor loop with a lag-lead network in the forward loop. The system had a velocity constant of 150 sec^{-1} and a bandwidth of 0.1 cycles per sec. with a closed-loop peaking of 1.3. However, in order to achieve this performance, the lag-lead network had time constants of 5,000 seconds and 500 seconds which are difficult to visualize physically. The second approach was made with a Type I system having a velocity constant of 70 sec^{-1} and a closed loop bandwidth of 0.2 cps. The largest time constant for this maximum bandwidth system was 66 seconds which is a reasonable size. Figure III C-4 is a Bode Plot summarizing this system. A third design effort was to resort to a Type II system, thereby eliminating all steady-state errors when tracking at a constant speed. Figure III C-3 shows a Bode Plot of such a system in the region of gain cross-over. This system also has reasonable time constants; however, the acceleration constant is extremely small. To better serve the function of meeting the pointing accuracy and adjustable bandwidth requirements, the details of the use intended for the bandwidth selector should be known. Perhaps a system which can be switched to a Type I during that period of operation when transients are taking place and then to a Type II system with minimum bandwidth during nearly constant speed tracking may be used.

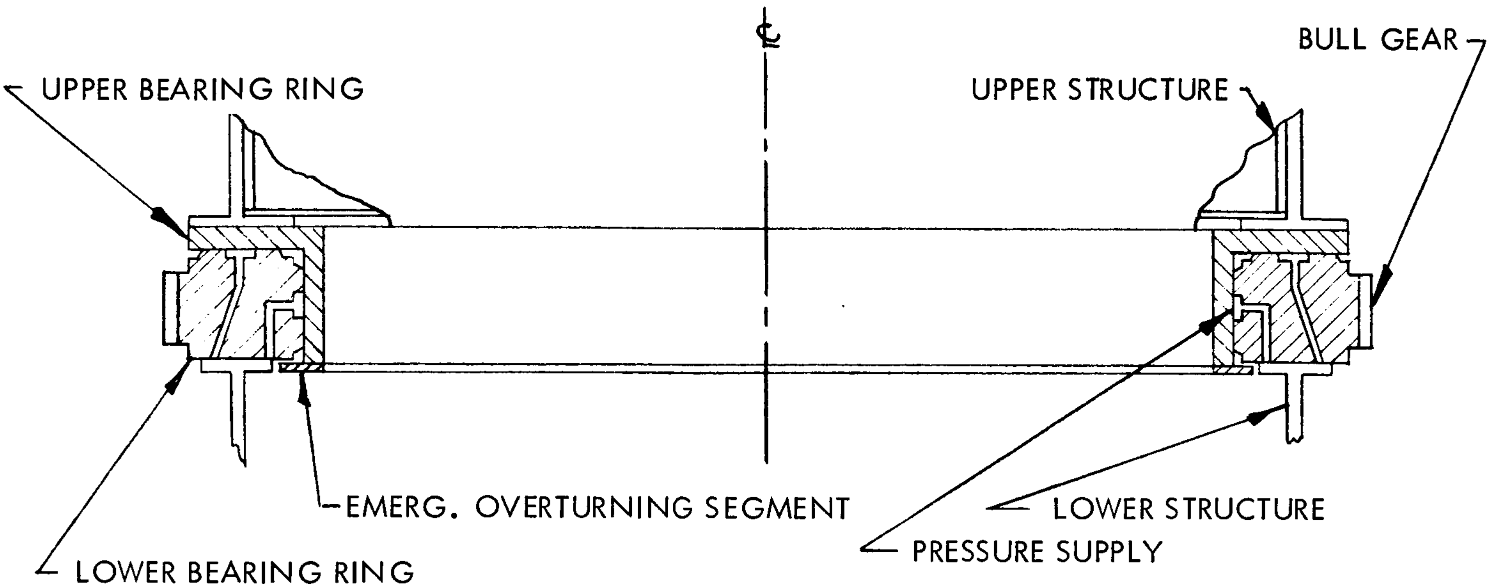


FIGURE III C-2
SECTION— AZIMUTH
HYDRO-STATIC BEARING

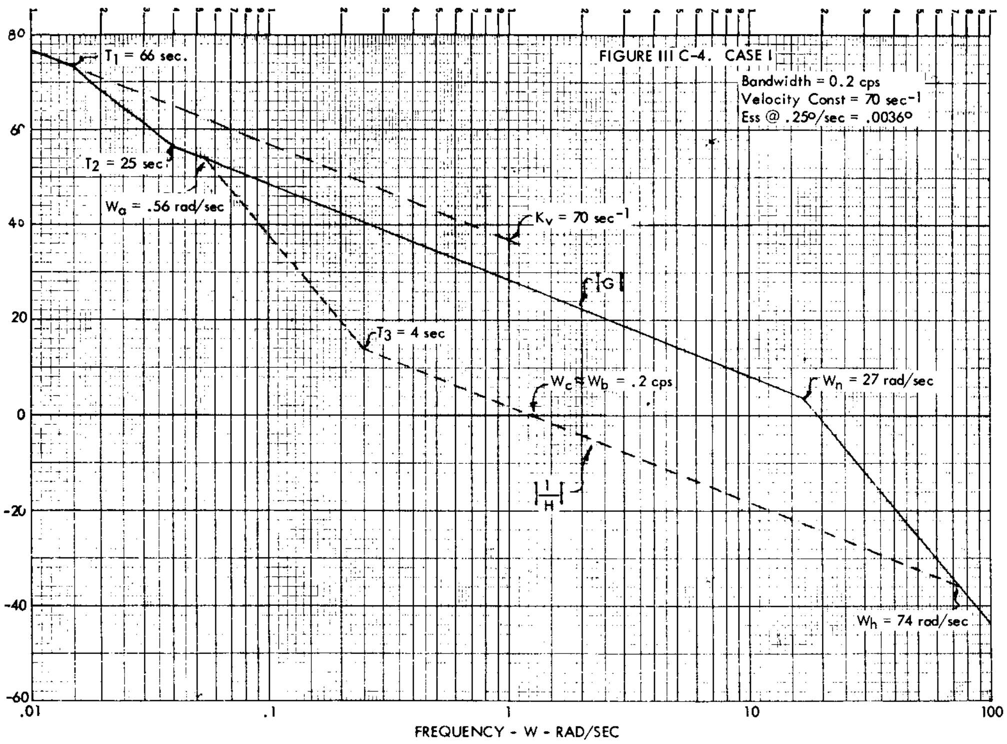
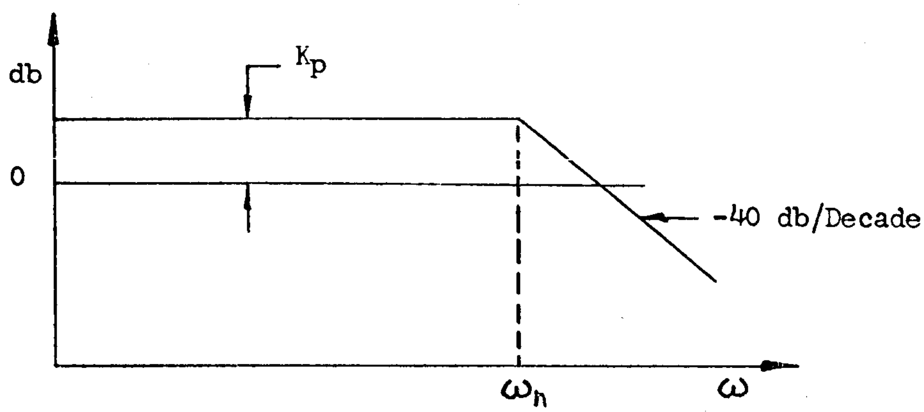


FIGURE III C-4

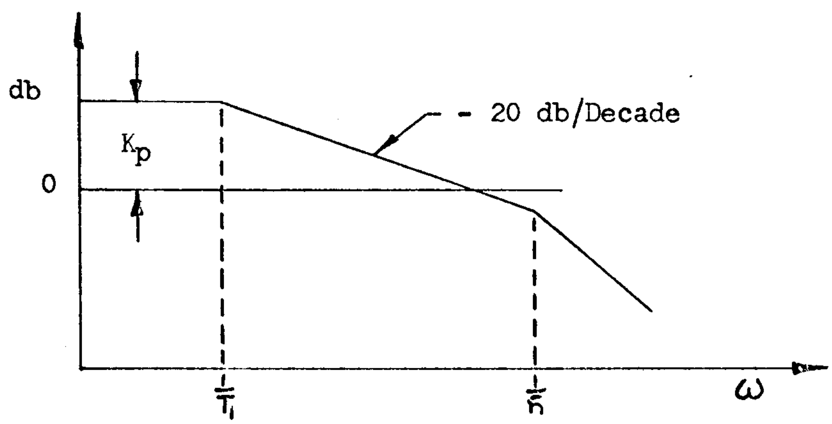
3. Manual Rate Operating Mode

The desired rate in each axis will be attained by rotating calibrated dials. Rotating a dial clockwise will cause that antenna axis to rotate in one direction at the rate indicated by the calibration marks, while rotating the dial in the opposite sense will cause opposite antenna axis rotation. In this manner, both rate and direction for a given axis are controlled from one dial. If the speed regulation requirement is tight, a small electric type 0 servo system will be used in series with the hydraulic power control system (assuming the power system is hydraulic). The output of the instrument servo system is a position command for the power servo system. The power system is a position servo while the small electric "pacer servo" is a velocity servo with position output. This is necessary because hydraulic systems make poor speed regulators. This can be seen by comparing the Bode diagrams of a hydraulic speed regulator and an electric speed regulator.



HYDRAULIC SPEED REGULATOR
OPEN-LOOP FREQUENCY RESPONSE

3. Manual Rate Operating Mode (Continued)



ELECTRIC SPEED REGULATOR
OPEN-LOOP FREQUENCY RESPONSE

Note that the hydraulic time constants appear in complex pairs while the electric system has widely separated time constants.

4. Secondary Reflector Control

A preliminary evaluation indicates the relative position of the secondary reflector may be seriously affected by thermal and elastic structural deflections, (due to wind loading). If so, this will require a servo control of the reflector to maintain its relative position. The control system will be basically similar and composed of similar components as those considered for the primary system.

5. Angular Rates

Tracking at extremely slow rates implies a stringent requirement on the smoothness of the control and drive system. This particular requirement tends to favor a hydraulic motor drive with a tight servo loop (high loop gain). This is one of the principal reasons such a system was chosen for the Haystack Antenna System. For this reason, together with the noise generation problem, a servo valve controlled hydraulic motor drive system will receive serious consideration during the Phase I study; though not to the exclusion of the electrical drives. Both systems will be carefully investigated and the expected performance data will be listed. The most promising system will be further refined to meet the minimum requirements and a trade-off between cost and meeting the design goal will be shown and discussed. Equally important for slow tracking are bearing stictions, gear granularity, motor breakout torque, etc. The experience gained on Haystack Hill can be directly applied to this study.

The prime mover and gear ratio selection will be a compromise between the slow tracking requirements and the maximum slew rate requirements which in turn are related to cost. This complex relationship will be shown during the design study as it relates to meeting the minimum requirements and also the design goals.

6. Angular Acceleration

The requirement is for an acceleration of $0.2^{o}/sec^{2}$. about both axes. The power required to drive each axis will be determined by the inertias, wind forces, weights as reflected in friction, and rotational speeds. Conservative engineering practice will be utilized in arriving at the power requirements in that the maximum wind torque, maximum acceleration torque and maximum speed will all be assumed to occur simultaneously. The antenna configuration will be refined with the goal in mind to minimize the power requirements and the reflected cost structure will be explored. In this manner the most efficient use of structure compatible with the antenna system requirements will result.

7. Pointing Accuracy

A similar requirement for attaining precise pointing accuracy was accomplished by North American for antenna project Haystack Hill. In this instance the system performance was obtained by using shaft position encoders, to measure antenna position. The encoders were mounted on a shaft at the centerline of the rotational axis. Thus, gear inaccuracies do not contribute directly to the control system inaccuracies, but being in the loop they affect stability. The maximum pointing error for the Haystack Hill application was present when maximum acceleration and velocity occurred simultaneously. However, in addition to these, the pointing error of the proposed JPL antenna system is subject to structural deflections caused by temperature variation and unbalanced wind loads. As a result of the thermal and elastic deflections, measurement of the antenna position by means of a stabilized platform is considered. This type of system would consist of a gimbal mounted platform on the antenna dish. The platform would be stabilized by an optical tracking servo using optical masers to maintain a position relative to light sources on the surface of the earth. Consequently the azimuth and elevation position would be measured by shaft encoders on the platform. To meet all of the system requirements it is possible that both a digital and analog encoder will be required. This part of the problem will resolve down to selection of components.

The realization of the optimum means of attaining the pointing accuracy will result from a weighted consideration of the complete system in terms of accuracy, cost, complexity, reliability, differential thermal expansion and deflections.

8. Bearings

The tentative selection for azimuth rotation is a hydrostatic bearing, approximately 40 ft. in dia., operating on a hydraulic pressure system of approximately 500 PSI. A sectional view of a proposed bearing is shown in Figure III C - 2. This choice is preferable from a friction standpoint as related to pointing accuracy and smoothness of operation. For this antenna, the force required at the motors for rotation under dead weight alone, with no acceleration, would be 70,000 lbs. (assuming a coeff. of friction = .05) for a rolling element bearing. The force required at the motors for a hydrostatic bearing would be 73 lbs.

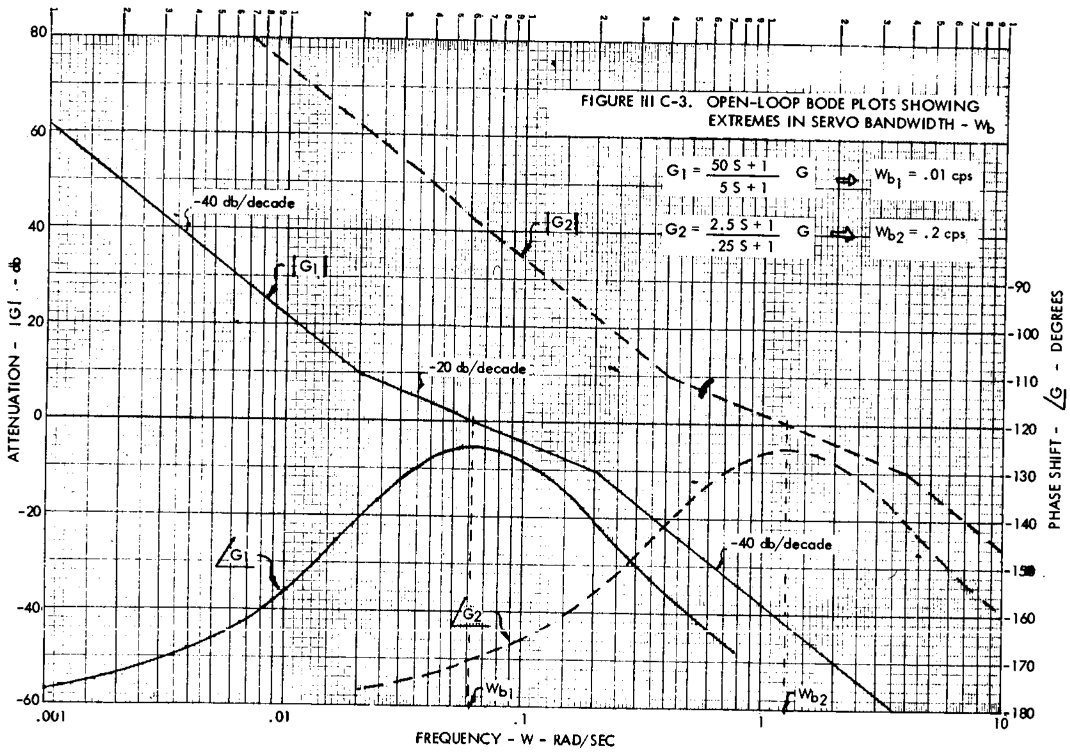


FIGURE III C-3

8. Bearings (Continued)

Problems relating to this selection are: machining, handling the overturning moments due to wind, and physical handling of the bearing.

The cost of a hydrostatic bearing would be equal to, or less than, a rolling element bearing at a 40 ft. diameter. The cost of tracks and rollers, and their effect on friction and back-lash will be investigated. Other variables to be evaluated for a rolling element bearing vs a hydrostatic bearing vs tracks and rollers, will be stiffness, stiction, failsafety, simplicity, and life.

The tentative selection for elevation rotation is a rolling element bearing, approximately 4 ft. in diameter. This choice appears desirable in that this size roller bearing is readily available, the diameter is small enough that friction is not prohibitive, and from a cost standpoint would be very favorable.

Problems relating to this selection are: differential expansion due to thermal expansion of the antenna structure and the support structure, alignment of the bearings, stiffness, and lubrication.

Problem solution will be achieved by selecting a bearing type, rolling element vs hydrostatic vs tracks and rollers vs sliding friction (bushing type) in terms of cost, friction, backlash, stiffness, stiction, failsafety, simplicity and life.

A hydrostatic bearing is now being designed by North American for the Haystack Hill Antenna.

III. SYSTEM DETAILS

D. POWER SYSTEMS

Power Systems include the supply and distribution of all fluid and electrical energy, conditioning and equipment cooling associated with the antenna system. In keeping with the general philosophy in the approach to the design of the proposed antenna system, primary consideration must be directed towards obtaining at minimum cost a high degree of reliability and maximum simplicity consistent with the operational requirements. The ability to provide completely "fail safe" operation is paramount and requires investigation into the varied potential hazards that can occur. All service points and maintenance areas must be readily accessible and safe to personnel. By utilizing existing and proven components and design concepts, a predictable high degree of reliability, long life, low maintenance, and economy are readily available. Development and advancements of the state-of-the-art should be applied only to those areas in which substantial gains in the above considerations can be realized.

1. Antenna Drive Power Supply

A power supply system tailored to the requirements of the antenna drive servo actuators will be required for elevation and azimuth control. This equipment with its associated controls will be contained in the machinery building near the base of the antenna. In addition to the drive machinery, associated equipment such as hydraulic reservoir, filters, gages, cooling heat exchangers, etc. will be located as practicable in the machinery building. Prime power will be electric (furnished by JPL).

A preliminary investigation of the power requirements for the antenna drive indicates a magnitude on the order of 250 to 300 horsepower will be required to drive the antenna under maximum load conditions. As envisioned at this stage of the investigation, a typical hydraulic power supply would be similar to the following description. Two motor pump combinations would be connected in parallel to supply the total hydraulic flow necessary for the maximum rate. The motors would be A.C. induction motors with "across the line" starters and would drive variable volume, pressure servo controlled, piston pumps through a straight coupling (no gear reduction). The motor-pump units would be isolation mounted, and acoustically enclosed. All gages, controls, a common reservoir, filters, etc. would be located outside the enclosure for accessibility and ease of maintenance.

Heat exchangers and air cooling for the induction motors would probably be required due to the acoustic enclosure of the machinery. Additional devices such as hydraulic desurgers and flexible lines would be required to reduce fluid and structure borne noise. The pumps would utilize dual range pressure compensators; the high range (on the order of 3000 psi) would be utilized for maximum load conditions resulting from operation during the 70 mph wind condition. Under normal conditions the pumps would operate in a lower pressure range (approximately 1500 psi).

The concept of two separate motor-pumps is suggested as a means to achieve fail safe operation and to enhance maintenance operations. Breakdown or maintenance on one motor-pump still allows operation of the antenna system at half rate and full load. A.C. induction motors of the squirrel cage variety are considered a reliable power source well suited for hydraulic pump drives with minimum electrical noise and long life.

Motors and pumps are sized for the same operating speeds (approximately 1200 rpm) thus allowing a straight coupling with no gear reduction. This eliminates one source of noise and the attendant lubrication, heat rejection, and wear of gear systems.

Preliminary investigation with potential equipment manufacturers indicates drive machinery both pumps and electric motors, normally produce noise levels on the order of 85db each. (AIEE standards are 90db maximum for electric motors). By some modifications these levels can be reduced somewhat, perhaps on the order of 5db. However, an overall airborne noise level of 75db, as required by the JPL specification, will probably require acoustic treatment as mentioned above.

Acoustic noise has been found to be directly related to operating pressures. It is thus beneficial to operate at lower hydraulic pressure when possible. It should also be noted, that as a general rule, longer life and better performance of hydraulic components can be obtained with lower operating pressures. However, study will be required to determine the optimum pressures to be utilized in the drive system.

It is recommended by this Contractor that noise level requirements be further amplified. The requirements of the planning document indicate the intent of JPL to control acoustic noise. In order to assure compliance with the intent of JPL and not place unwarranted emphasis and expense on noise abatement and control, it is recommended that limits be considered and coordinated between JPL and the Contractor. These limits should include airborne, fluid borne and structure borne noise and allowable frequency spectrum profiles.

Limits should be considered for both local areas near noise generation points and general noise levels in buildings and enclosures.

2. Lubrication System Supply

Lubrication is required of the bearings of the antenna mount. Lubricating oil must be supplied under pressure to the rolling bearings and hydrostatic bearings. Included in the supply must be a system of pressurization, control, filtration and cooling. The system, other than distribution elements will be designed for compact installation to facilitate maintenance and minimize potential leakage connections. Prime power will be electric (furnished by JPL).

Preliminary investigation of potential antenna mounts for the system indicates a probable hydrostatic azimuth bearing and a roller bearing for elevation. The initial concept for this system is to provide a central pressurized supply for all bearings. A variable displacement pump driven by an A.C. induction motor, with integral reservoir, filter and controls would supply the lubricating oil under pressure to the bearing systems. Oil would be returned by gravity flow. The combination, for economy of both lubricating and hydraulic oil cooling into an integral assembly will be evaluated. Large flywheel and accumulator provisions would be utilized for the possible event of power failure. Two pumping units could be used for bearing safety at relatively small cost. Acoustic and electrical noise will be treated in the same manner as those similar problems in the antenna drive system.

3. Electronic, Equipment and Structural Cooling

Cooling for several items in the antenna system will be required. Among these items will be much of the electronic equipment, antenna drive power supply, lubrication supply system and possibly portions of the antenna structure. From a cost standpoint it is believed that much of the electronic equipment can be convection cooled, and thus integrated with the air conditioning. Acoustic confinement of some equipment may be required to meet the 50db noise level requirement in the controls building. Forced air can be considered in some cases; however, such methods may produce objectionable higher frequency noise. Liquid cooling must be considered, especially where acoustic noise may be a problem. Economic considerations must be evaluated for cooling equipment and operating costs. Inasmuch as an unlimited water source underground heat sink is not available (water being trucked in from 20 miles away), it appears likely that heat must be eventually dissipated through liquid-to-air heat exchangers. Centralized cooling will be considered where economically feasible; however, centralization may be limited to individual buildings. In the following discussion of conditioning and heating it will be shown that integration may be possible with the equipment and electronic cooling.

4. Environmental Control

Heating, cooling and humidity control will be required in the building and enclosures, including the controls building, machinery building and the antenna equipment room. Although the controls building and services are JPL furnished, a coordinated effort will be required between the Contractor and JPL. It appears that by using liquid heating and cooling with forced air circulation it is possible that the heat rejection from equipment cooling may be utilized to augment the heating system(s) for the installation. From the geographic location of the Goldstone installation, humidity control does not appear a design problem; however, the equipment requirements and moisture rejection of personnel within enclosures such as the antenna equipment room must be evaluated.

Conditioning of the antenna equipment room will require consideration of the 60db noise level requirement. Liquid coolant from an integrated cooling system may be considered; however, it is felt that quiet panel mounting of a window type air conditioner for heating and cooling may prove satisfactory. Special attention will be given if found necessary to possible acoustic treatment of air duct linings and isolation mountings.

Although not specifically mentioned in the JPL specification, it is felt that consideration should be given to a degree of heating and cooling in the machinery building. This area will be investigated.

5. Power Distribution System

The power distribution system consists of picking up from the JPL supply (60 cycle - 3 phase) and includes conversion and distribution of power with related interlock controls for antenna drive, conditioning, electronics, cooling, lighting, etc. Included is cabling for operation of the mount, coolant power and wrap up system at points of rotation on the antenna.

A study will be required to coordinate the optimum distribution of power within the installation between JPL and the Contractor's pickup points. An overall evaluation is necessary in the interest of economy for the entire installation. For example, lower cost of the less intricate "across the line" starters for electric motors may be offset by the increased capability required of the JPL electrical supply of power. Conversely, should the cost be greater than the benefits of the above, reduced voltage starters may prove desirable, especially for the antenna drive power supply.

A similar evaluation will be required of voltage requirements. Although 440 volt power appears economical for contractor supplied components a coordinated effort is required to appraise higher or lower voltage supplies.

Included in the study of distribution of power will be installation, radio noise and shielding consideration for all cabling and installation and design of the cable wrap up systems on the antenna mount. A coordinated study effort will be made of the necessary interlock, safety and remote controls required for the antenna system.

In the design study of an optimum cable wrap up system past the points of rotation of the antenna this Contractor will utilize to the fullest extent possible the experience gained in the design of the current Haystack antenna system and the experience of JPL and other agencies in the operational development of existing major antenna systems. Considerable effort has been expended by this Contractor in the design of the Haystack system and it is believed that with modification the basic design is readily adaptable to the JPL (DSIF) system. With a limit on the range of azimuth travel, a "cable reel" is provided with each service or cable forming a spiral on its individual stationary tray. One end of each cable is fixed to the base and the other end to a follow-up shaft which rotates with the azimuth elevation mount. The follow-up drive shaft is driven by a servo controlled hydraulic motor powered from the antenna drive hydraulic power supply. All cables are protected from abrasion by proper casing and nylon runners.

IV. SYSTEM PERFORMANCE SUMMARY

This section follows the order of Section 5. "System Specifications" of JPL Engineering Planning Document No. 5, Rev. 1, and recapitulates the performance data on the NAA Columbus Division's Advanced Antenna System Concept.

A. SYSTEM PERFORMANCE AND OPERATIONAL CAPABILITY

1. Antenna Mount

a. Accuracy

The antenna is a Cassegrain system, azimuth-elevation mounted on a concrete pylon. The reflector structure design is based on an axial-load concept developed by NAA during studies over a period of several years. The reflector system structure is supported at its natural load application points, and is the most rigid possible at lowest cost and weight. Structural deflections have least effect on performance in the proposed configuration. A hydrostatic azimuth bearing removes static friction that would otherwise degrade the performance.

The microwave aspects of the reflector and mount are discussed in Section III-A, and the structural considerations in Section III-B. The approach to the problems, the variables to be examined during the Phase I study, and the optimization work to be done are also discussed. The Phase I effort described will lead to a design for an Advanced Antenna System meeting the accuracy requirements.

b. Resonances

The stiffness of the reflector structure and the balanced mounting structure are described in Section III-B. It has been shown that the resonant frequency of the reflector structure will be above 3 cps. Consideration of earthquake-induced forces on the supporting pylon indicates that the resonant frequency of the pylon should not fall in the range 2.5 to 5 cps (III-B).

c. Acceleration Limits

The structure and drive system can be designed to withstand angular accelerations of $1^\circ/sec^2$ about both axes.

d. Foundation

The concrete mounting pylon will rest on a concrete foundation with footings designed for a nominal bearing strength of 2000 lb/ft^2 and a lateral bearing capacity of 300 lb/ft^2. Actual soil characteristics will be verified and the bearing capacities modified as required.

e. Access to Structure

The panels comprising the reflector surface will bear a 300 lb. man wearing "snowshoes" of 4 ft^2 area/shoe. Necessary walkways, platforms, ladders, etc. for access will be part of the design, and will provide for the safety and convenience of personnel.

f. Safety Considerations

Standards of good engineering practice will be followed throughout the design, and the requirements of the California State Industrial Safety code will be met wherever applicable. Interlocks on the elevation axis will prevent irradiation of personnel with UHF transmitter energy, and interlocks on the access platforms, walkways, etc. will prevent energizing the transmitter when personnel are in the microwave paths.

g. Equipment Room

An equipment room will be gimbal-mounted close to the vertex of the paraboloidal reflector so that the working area remains level. The transmitter output amplifier and receiver preamplifier will be installed in the structure under the feed support, so that waveguide runs are short and direct. Power and coolant lines are equipped with "wrap-up" devices, permitting rotation in elevation. The working area is air conditioned, with acoustical treatment of the equipment to reduce noise to less than 60 db.

2. Servo and Control System

a. Angular Coverage

The system proposed by NAA Columbus provides for 600° azimuth angle range, and 182° elevation angle range. "Plunging" capability is a feature of the design.

b. Angular Rates

(1) Tracking - The antenna is hydraulically driven with closed-loop servo control, as described in Section III-C. A problem arises in attempting to meet the provision for variable servo bandwidth from 0.01 to 0.2 cps along with all other requirements, because of large time constants in the lag-lead network (III-C). This problem may be solved by a dual-mode system, or by other approaches to be investigated during Phase I.

The requirements of 0.008°/sec in Hour Angle, and 0.001°/sec in Declination (both variable down to zero) can be met in the proposed approach.

(2) Slewing and Scan - In slewing and scan modes of control (described in Section III-C), the requirement of 0.25°/sec down to zero rate will be met.

c. Angular Acceleration

(1) Slew and Scan - It was assumed that maximum wind torque, maximum acceleration torque, and maximum speed may occur simultaneously. The proposed system is conservatively designed, with power adequate for acceleration of $0.2^{\circ}/sec^2$ about both axes.

(2) Tracking - The $0.2^{\circ}/sec^2$ acceleration about both axes permits tracking a "Standard Target".

d. Pointing Accuracy

(1) Position Command - To meet the requirement set for automatic tracking, the pointing error for each axis must be held to $\pm$ 0.007 peak at 0.5°/sec. This will enable meeting the Position Command requirement of 0.02° peak at slow rates.

(2) Automatic Tracking - Holding the error for each axis to $\pm 0.007^{\circ}$ peak at 0.5°/sec requires a servo velocity constant approximately 72 sec^{-1} for a Type I servo. At a closed loop bandwidth of 0.2 cps, the largest time constand is 66 seconds, which is a reasonable value. The requirements can be met at 0.2 cps bandwidth. A considerable engineering effort is required before stating that the requirements can be met with a servo bandwidth of 0.01 cps, or before stating what minimum bandwidth can be provided without excessive cost or complexity.

e. Servo Bandwidth

Time constants of 5000 sec. and 500 sec. are required in the lag-lead network of a Type I system with velocity feedback. These may not be physically realizable, and the initial approach may require modification during Phase I. The 0.2 cps bandwidth requirements can be met; the minimum bandwidth cannot be specified in advance.

f. Operating Modes

(1) The slew mode with proportional control by manual lever, at rates variable from zero to maximum, will be provided. Operation of the lever will control either axis or both simultaneously.

(2) Manual position will be provided by two handwheels rotating synchro transmitters through high ratio gearing to prevent "null skipping" at maximum speed. Digital displays will indicate antenna position.

(3) Rotation of calibrated dials will provide Manual Rate (Aided Track) capability. Clockwise rotation causes rotation in one direction at a rate indexed by calibration marking on the control. A Type 0 electric servo in series with the hydraulic power system is used, since hydraulic systems are poor speed regulators.

(4) No major problems are foreseen in designing the servo system to meet the requirements, operating from an input of 7 volts/0.1°, ± 4 volt max. The major problems, discussed in Section III-C, are in designing a servo with enough gain to meet the pointing accuracy requirement, and with 0.2 to 0.01 cps bandwidth.

(5) The precision control system uses digital transducers and associated equipment, and is thus compatible with Slave Mode commands from 5-hole punched tape.

(6) Coordinate conversion equipment and processes are used to convert Sidereal Hour Angle and Declination Angle data to Azimuth-Elevation angle data. Design of a system to hold accumulated position bias error to less than 0.005° after 10 hours will be accomplished during Phase I.

g. Scan Generator

The Scan Function Generator for Elliptical Spiral or Sawtooth Scans may be electronic or electromechanical. NAA has experience in development and design of both types, and will make a choice during Phase I on the basis of accuracy, simplicity, and cost.

h. Servo Control Console

The Servo Control Console will provide for selection of any mode from any other mode, with interlocks to prevent system transients during mode selection.

i. Control Console, Portable

A portable control console will be provided, incorporating readouts, controls, and interlocks to prevent system transients when the console is engaged.

j. Servo Electronic Equipment

The servo electronic equipment will use proven designs and components. The equipment will be developed and tested, and supplied in equipment racks. Testing provisions will be included. Failure or malfunction will not cause disastrous consequences to the antenna.

k. Safety Devices

(1) "Fail-safe" requirements in control systems are normal to NAA, as failure of an aircraft control would otherwise mean loss of the vehicle and possibly of human life. In the Advanced Antenna System, there will be no catastrophic consequences of the failure or malfunction of the control system.

(2) Azimuth and Elevation limit switches and limit stops will be provided in the system.

l. Operation Warning

Aural and visual warning will be provided at several points in the Advanced Antenna System installation. These warning lights and horns will be interlocked with the Key switches controlling the drive.

m. Key Switch

Key-actuated switches in the control and power buildings will control the antenna drive. The two will be interlocked, and be provided with position indicators.

n. Emergency Stop Switches

Key points, including points of access to, around, and on, the rotating portion of the structure will be provided with emergency stop switches.

o. Drive Power Building

A weatherproof building large enough to house drive power equipment, plus a 30' X 30' X 12' volume for JPL-supplied power supply equipment, will be furnished. Acoustical treatment, described in Section III-D, will reduce the noise level to less than 75 db.

3. Antenna Axis Digital Readouts and Display Devices

Antenna position will be indicated digitally by arabic-numeral indicator lamps mounted in a rack above the servo control console. As described in Section III-A-3, the accuracy will be $\pm$ 0.002° peak or better, and the resolution within 0.001. BCD output to a JPL data-handling system will be supplied, with an output to the contractor-supplied slaving system. Mechanization for sidereal hour/declination angle readouts will be supplied with an accuracy of $\pm$ 0.006° or better.

4. Gain and Antenna Temperature

The reflector system is a microwave analog of the Cassegrain optical system. The paraboloidal (major) reflector is 270 ft. diameter, and the hyperboloidal (minor) reflector will be optimized, at about 30 feet. The effects of non-uniform illumination, deflections, and side-lobe levels are discussed in Section III-A-1.

a. The figure of merit in the receiving case has been discussed, in terms of the noise temperatures which may actually be achieved for the remainder of the system. The proposed reflector system will have an effective area of 35,500 sq.ft. This corresponds to an increase in the Receiving Figure of Merit of 15.2 db for the 20° K temperature assumed. If the total system noise temperature is 40° K, the increase is 12.2 db; and if the temperature is 60° K, the increase is 10.4 db.

b. The transmitting gain of the proposed system has been computed as 63.0 db, which is 11.1 db above the reference value and 5.1 db above the minimum acceptable value.

5. Feed System

a. S-Band Transmitter Feed

The S-Band transmitting feed is a double-ridged square horn whose bandwidth is sufficient to serve also as a receiving collector when automatic tracking is not required.

(1) The feed will safely handle 120 KW average power under all specified environmental conditions.

(2) The gain/pattern characteristics will be as required for illumination of the hyperboloidal reflector.

(3) As described in Sections III-A-2 and III-B-2, the structure will rigidly support the feed in the proper position determined by the boresighting process.

(4) The bandwidth is more than the required 20 Mc/s.

(5) The input VSWR will be less than 1.05 over a 20 Mc/s band centered on 2115 Mc/s, and a similar ± 5 Mc/s band centered on 2295 Mc/s.

(6) Polarization will be circular, with provision for rapid change of its direction of rotation.

(7) Losses will be minimized by eliminating all possible dielectric material, to assure compatibility with overall system loss requirements.

b. S-Band Listening Feed

The data given in paragraph 5.a. above apply, since the feed is used for both purposes.

c. S-Band Tracking Feed

A set of four double-ridged square horns is used as a simultaneous lobing feed.

(1) Reference channel pattern/gain characteristics will be such as not to degrade the performance by more than 2.5 db. Sidelobe levels beyond 2° from the axis of the main beam will be down at least 52 db from the main beam (III-A-1).

(2) Error Channel Pattern characteristics will not be down more than 15 db from the "sum" channel peak. The requirements on slope, sidelobes, null depths, and cross coupling will be met.

(3) Alignment and stability will be compatible with requirements, using the techniques described in Section III-A-2 and III-A-3.

(4) The bandwidth will be at least ± 5 Mc/s centered on 2295 Mc/s.

(5) The VSWR over the operating band will not exceed 1.1.

(6) Right or left circular polarization will be provided.

(7) Isolation between reference and error channels will be 40 db or better, and between error channels will be better than 30 db.

(8) Losses will be minimized by elimination of all dielectric material, and will be compatible with system requirements.

d. Feeds for Other Frequencies

The reflector system will be capable of operation at 890 and 961 Mc/s. The design feasibility will be substantiated during the Phase I study. Consideration will be given to the feasibility of operation at 400, 1425, and 1700-1710 Mc/s.

e. Feed Handling

Rapid interchange of feeds is accomplished with mininal use of tools by mounting the feed horn above a rotating structure which is held by spring clamps rather than bolts. A half turn of the structure causes the horn to be switched from transmitter to receiver or vice-versa. This operation should require 1/4 minute or less, allowing 1-3/4 minutes for transmitter shut-down and a man to enter upon the feed mount.

Changing to automatic tracking feed requires replacement of the single horn and mount by the four horn cluster, duplexer and mount. Minimal use of tools is required, and the operation can be performed in less than the specified 1/2 hour.

Indexing detents and the spring loading ensure alignment of feeds. The strength of the assembly should provide over 40 cycles without loss of alignment precision.

6. Radio Receivers and Transmitters

NAA will coordinate with JPL to assure complete compatibility of NAA equipment with the JPL-supplied receivers and transmitters.

7. Antenna Instrumentation

a. Test Fixtures and Equipment as required for system evaluation will be supplied. Test procedures and an indication of the types of equipment required are discussed in Section III-A-3.

b. Boresighting equipment, consisting of optical telescope(s), TV equipment, and associated equipment for boresighting the antenna are described in Section III-A-3.

8. Cabling and Coolant Lines

a. Cabling systems for the antenna system will be designed during Phase I. Facilities to supply power and coolant to the transmitter output and receiver input amplifiers will be designed and provided. Twenty convenience outlets (115 volt 15 amp) will be distributed around the antenna mount.

b. Cabling as required for system operation will be designed and provided. Exposed cabling will be protected in channels, cableways, and by other suitable methods.

9. Data Handling

NAA will assure compatibility with JPL-supplied digital angle transmitting and recording gear.

10. Timing

JPL-supplied timing to one part in 10^8 will be used.

11. Facilities

a. JPL will designate the site during the later stages of the Phase I study.

b. JPL-supplied power (60 cycle, 3 phase), regulated ±1% in frequency and ± 0.5% in voltage, is acceptable to NAA.

c. The JPL-supplied control building requires acoustical treatment when equipment is installed. NAA will coordinate with JPL to ensure complicance with the acoustic noise requirement of 50 db or less.

d. NAA will pay toll charges on the JPL-supplied telephone and teletype lines.

e. NAA will provide the intra-site telephone system (4 circuits, 12 or more stations).

12. Environment

The Advanced Antenna System will be designed and manufactured to perform within final specifications under any combination of:

Temperature - 0° to 135° F.
Sunlight - partial or complete exposure (except direct on the optical axis.
Humidity - 0 to 100% relative
Rainfall - 0 to 1/2 inch/hr.
Winds - to 30 mph, full performance
- to 45 mph, degraded by 2 times in accuracy, 2 db in gain/figure of merit
- to 60 mph, degraded by 4 times in accuracy, 5 db in gain/figure of merit
- to 70 mph, antenna can be driven to stowed (zenith) position from any other position
- to 120 mph, without damage if in stowed position

Lightning protection will be provided according to good engineering and safety practice.

Bearings will be bypassed against surges.

Ice and Snow loads, in amounts of 1" and 1' respectively, can be supported without damage with the antenna stowed.

Horizontal loads from earthquake-derived accelerations of 0.2 g can be sustained without damage.

13. Electrical Noise

Noise from all sources will be held below 10^{-23} watts/cps at the terminals of the feedhorn, in the interval 400 to 10,000 Mc/s. At frequencies below 400 Mc/s noise may increase as $1/f^2$ to a maximum of 1.6×10^{-20} watts/cps.

14. Supplement Material

NAA will request some of the offered JPL specifications and reports during Phase I.

B. DESIGN TECHNIQUES

All detail design, fabrication, assembly and rigging techniques and processes used will be within current "state-of-the-art" to the maximum possible extent. Fine precision in the antenna will be obtained by reduction of structural deflection caused by deadweight and environmental loads to a minimum, this being a feature inherent in the axial-load design concept. All repetitive deflections will be programmed out of the pointing systems, and the antenna will be rigged to minimize other error-producing deflections. Thermal deflections of the minor reflector will be removed by forced cooling of the reflector or by servoing the reflector face if this proves to be a necessity. The design will be substantiated analytically and by model testing.

The procurement and quality control specifications to be utilized will be specified.

Design factors employed in the course of the design will be specified.

All element designs will incorporate at least the following design features:

Low maintenance requirements, and ease of accessibility, for maintenance and repair.

Convenient and safe access to all RF components.

Catastrophic results will not occur due to mishandling or drive system failures.

Personnel safety provisions will be made as required to facilitate all phases of operation, adjustment, and maintenance of the antenna.

Design life of ten years with a use factor of 25% will be achieved.

A high reliability will be designed into the antenna system and a spares provisioning and maintenance concept evolved. This will ensure less than .01 probability of shut-downs for a five hour period at any time in the life of the antenna. The first two years of operation will be guaranteed[redacted]

V. REFERENCES

1. "The Effective Noise Temperature of the Sky", David C. Hogg and W. W. Mumford, Bell Telephone Laboratories, Whippany, New Jersey. Paper printed in the March, 1960, Microwave Journal.

2. "Design of Circular Apertures for Narrow Beamwidth and Low Sidelobes", T. T. Taylor, TM 372, Microwave Laboratory, Hughes Aircraft Company, Culver City, California, August 1954.

3. "A Monopulse Cassegrainian Antenna", Robert W. Martin and Leon Schwartzman, Sperry Gyroscope Company, Great Neck, N.Y.

4. "Final Engineering Report on Antenna Noise Temperature", Airborne Instruments Laboratory, Inc., Report No. 3304-11; November 1957 Contract DA-49-170-sc-1547.

5. "Physical Limitations on Antennas," Research Laboratory of Electronics, Massachusetts Institute of Technology, Technical Report 248; October 30, 1952.

6. "Low Noise Antennas", Robert C. Hansen, Hughes Aircraft Co., The Microwave Journal; June 1959.

7. "Side-Lobe Conference", Naval Research Laboratory, Washington, D.C.; 28 April 1952.

8. "Problems in Low Noise Reception of Microwaves", D.C. Hogg, Bell Telephone Laboratories, Fifth National Symposium, 1960, on Space Electronics and Telemetry, Washington, D.C.; September 19-21, 1960.

9. "Study of Cassegrain Antenna for Radar Telescope", Peter W. Hannan, Wheeler Laboratories, Inc., Report 853 (To Cornell University); October 24, 1958. Included as Appendix A in "Design Study of a Radar to Explore the Earth's Ionosphere and Surrounding Space", W. E. Gordon, H. G. Booker, B. Nichols, Cornell University, Research Report EE 395, Engineering Report No. 3; 1 December 1958.

10. "Nike-B X-Band Research Antenna", D. S. Lerner, Wheeler Laboratories, Report 677, ASTIA Report AD 305999. (Confidential).

11. "Nike-B X-Band Research Antenna - Boresight Alignment Tolerances", D. S. Lerner, Wheeler Laboratories, Report 678, ASTIA Report AD 305998, (Confidential).

12. S. Sandler, "Monopulse Far Field Patterns," Lincoln Laboratory Group Report No. 315-1, July 23, 1959.

VI. DRAWINGS

On the following pages three drawings (Figures VI-1, VI-2, and VI-3) are shown to aid in visualizing the Advanced Antenna concept presented in this proposal.

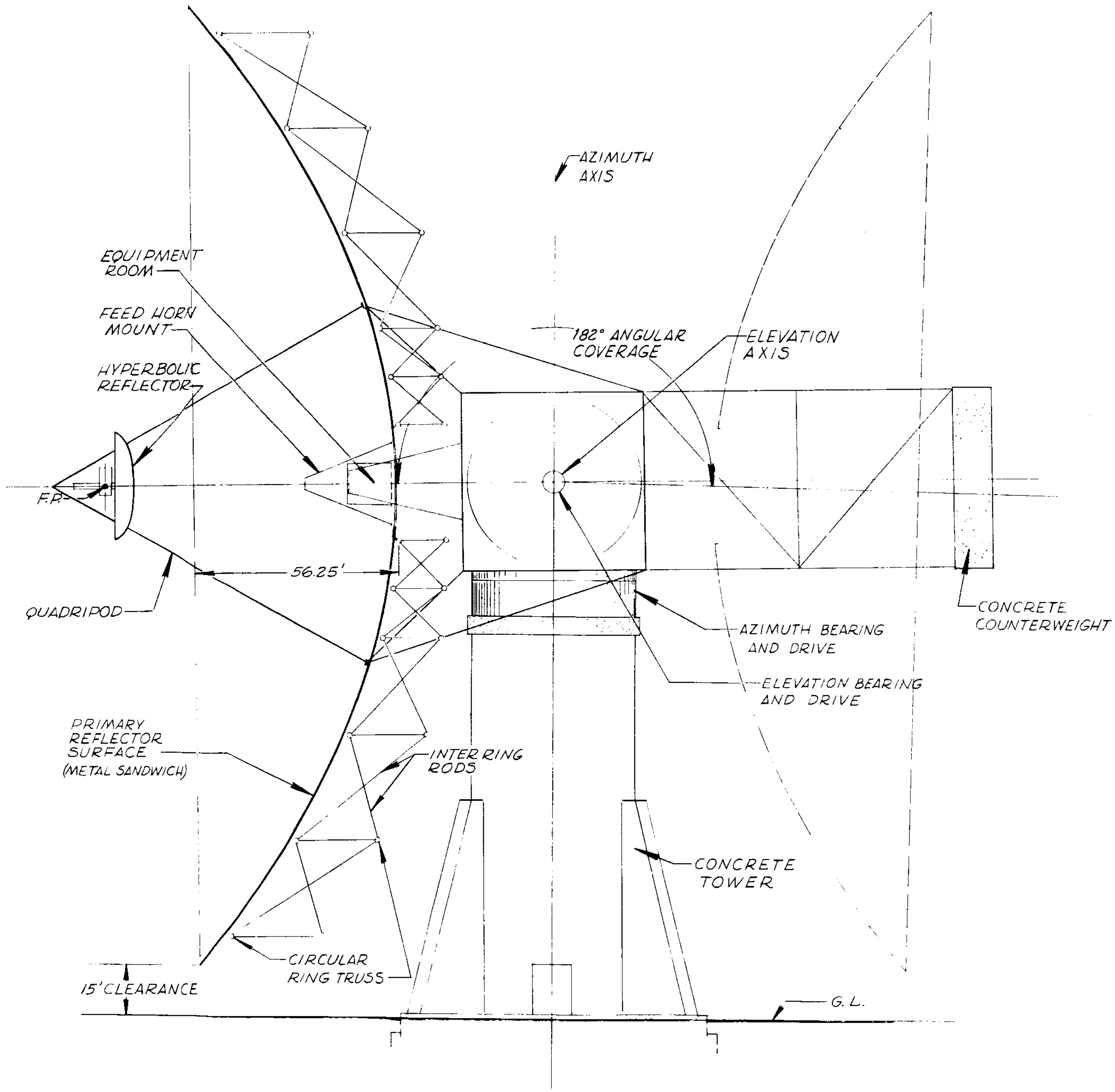


FIGURE VI-1
SIDE ELEVATION & ANGULAR COVERAGE

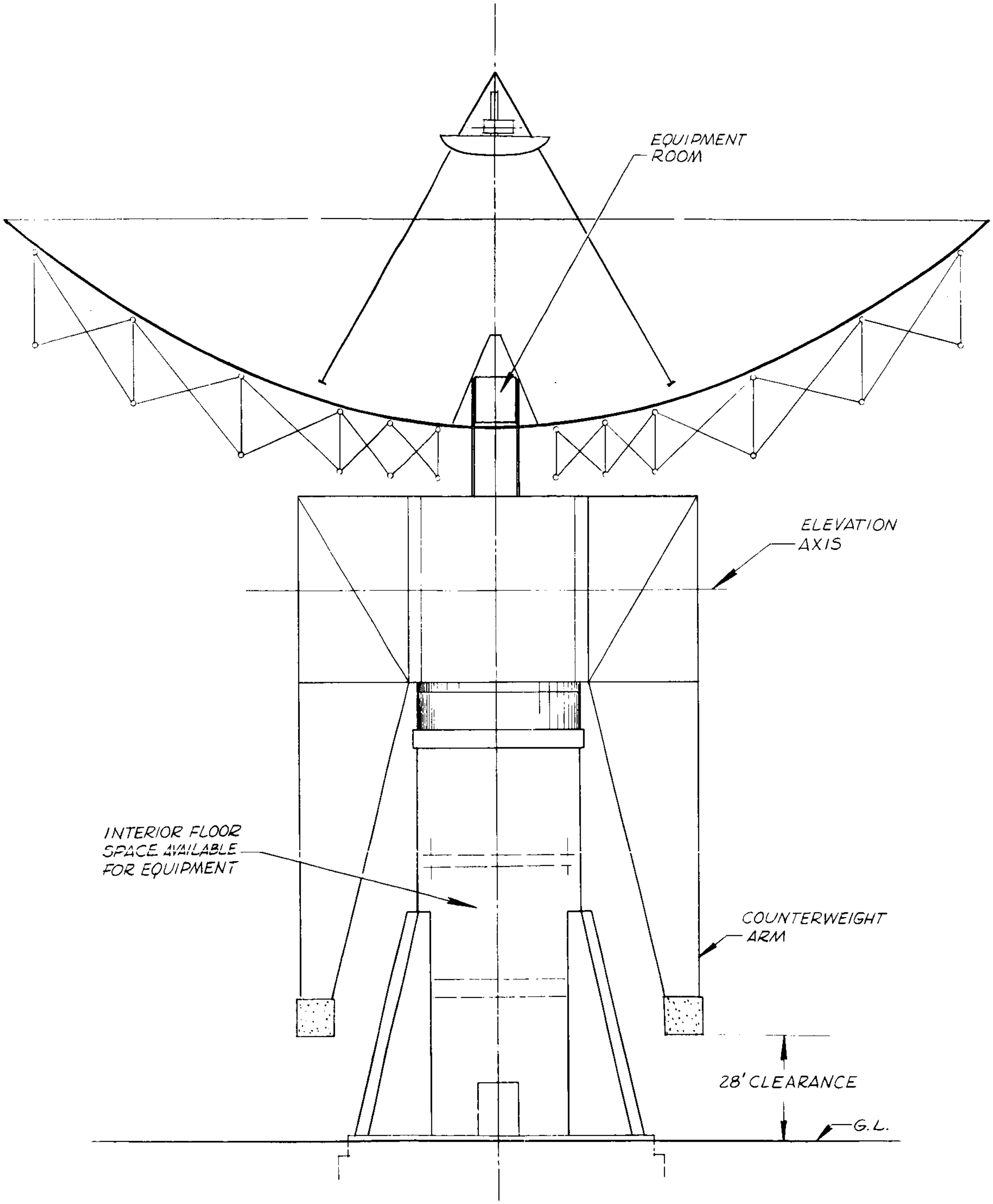


FIGURE VI-2
FRONT ELEVATION & BALLAST FRAME CLEARANCE

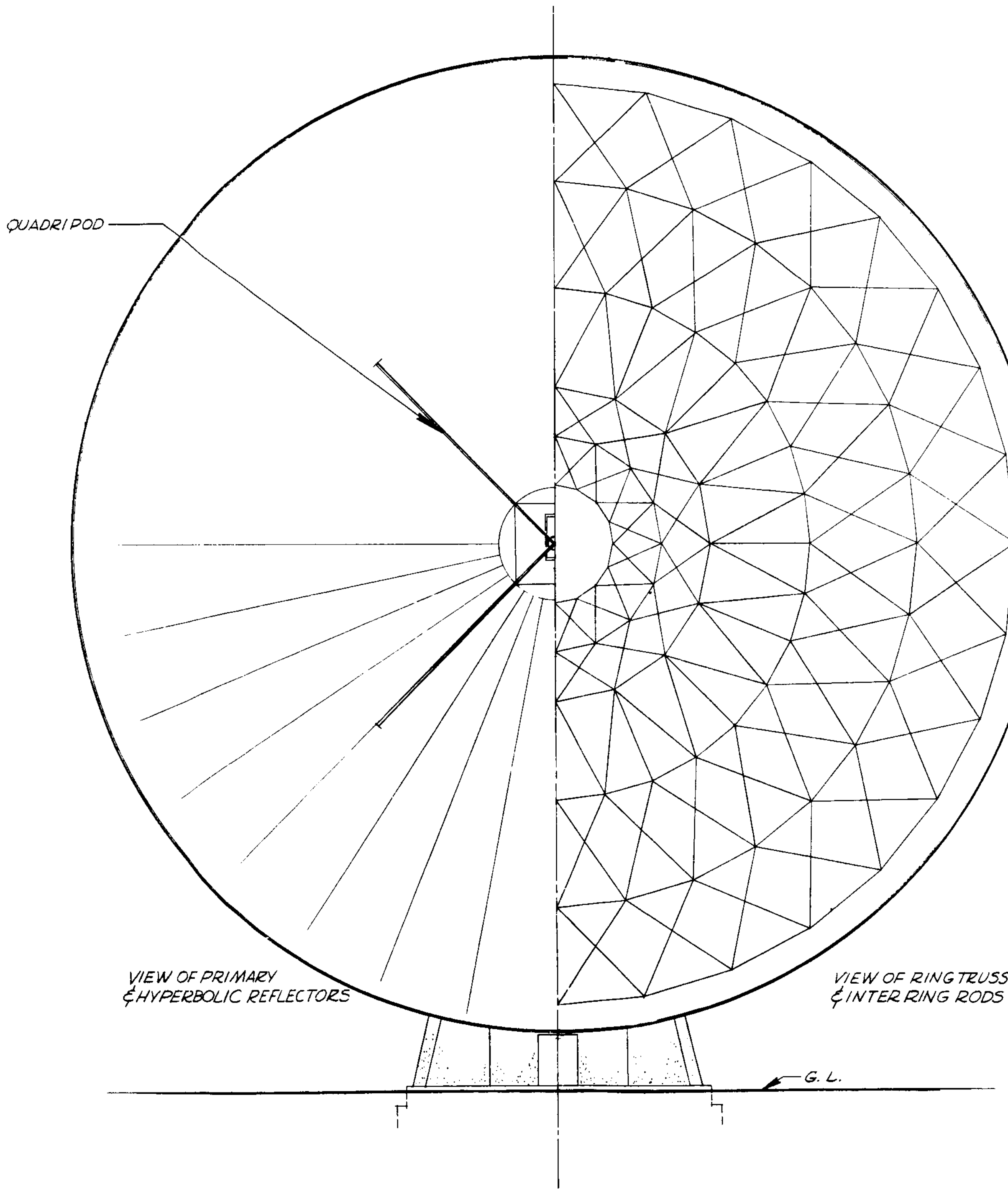


FIGURE VI-3
PRIMARY REFLECTOR STRUCTURE DIAGRAM

APPENDIX A

STATEMENT OF WORK

1. SCOPE. - This statement of work describes the requirements for a feasibility and design study of a large ground-based advanced antenna system for Jet Propulsion Laboratories Deep Space Instrumentation Facility.

2. APPLICABLE DOCUMENTS. - The following documents shall apply to the extent specified herein, and shall be the issue in effect on the date of the invitation to bid.

<u>Specifications</u>

<u>Jet Propulsion Laboratory</u>

Engineering Planning Document No. 5, Rev. 1	Project Description Advanced Antenna System for the Deep Space Instrumentation.
JPL 20017	Reports

3. REQUIREMENTS

3.1 <u>General</u>. - The Contractor shall conduct a study program to design an antenna system to meet the technical requirements of Section 5, JPL Engineering Planning Document No. 5, Rev. 1, dated 12 October 1960. A technical proposal for an optimized design developed during the study shall be provided.

3.2 <u>Study Program</u>. -

3.2.1 <u>Preliminary Design</u>. - A preliminary design of a recommended antenna system shall be provided.

3.2.2 <u>Cost</u>. - The relationship between antenna system cost and gain improvement (between 6 and 12 db) over the existing DSIF 85-foot antenna shall be investigated for both the receiving and transmitting modes of a nontracking feed.

3.2.3 <u>Fabrication, Transportation, Erection, and Acceptance Testing Methods</u>. - Fabrication, transportation, erection, and acceptance testing methods shall be investigated to determine any critical or unusually difficult problems and to develop methods to solve these problems.

3.2.4 Technical Proposal. - A technical proposal shall be provided as a portion of this study and shall consist of:

(a) Preliminary equipment specifications
(b) An antenna system detail specification
(c) Suggested design procedures
(d) Time schedules
(e) Cost estimates
(f) Manpower requirements
(g) Project management structure.

3.2.5 Design Techniques. -

3.2.5.1 Materials. - The Contractor shall provide a list of existing specifications which shall be utilized for the procurement of basic materials and parts.

3.2.5.2 Design Factors. - Design factors utilized during the study shall be specified.

3.2.5.3 Design Practices. - As long as the performance and cost of the antenna are not significantly affected, the conservative engineering design practices described in JPL Engineering Planning Document No. 5 Section 5b.(4) shall be considered.

3.2.5.4 Maintenance. - A spares and maintenance philosophy shall be evolved during the study to meet the requirements of JPL Engineering Planning Document No. 5, Rev. 1

3.2.6 Additional Frequencies. - In addition to S-Band studies, sufficient investigation shall be made to determine if the proposed antenna shall be capable of high efficiency use at the following frequencies:

890 to 891 mc (transmitting 1-10 KW)
960 to 961 mc (listening, tracking).

Also, degree of operation feasible at the following frequencies shall be investigated:

400 to 406 mc (listening)
1420 to 1430 mc (listening)
1700 to 1710 mc (listening).

3.2.7 Schedule. - The program shall generally conform to the schedule attached hereto.

3.2.8 Liaison. -

3.2.8.1 Technical Representation. - A Technical Representative shall be designated by the Contractor within one week following the awarding of the contract. All technical contact, involving technical data only, shall be made between the Contractor's technical representative and the JPL Advanced Antenna Project Director. All correspondence submitted to JPL shall consist, as a minimum, of one original and two copies, one copy of which shall be for Ozalid reproduction.

3.2.8.2 Technical Meetings. - Formal technical meetings shall be scheduled between JPL and the Contractor approximately every two months. The Contractor shall present a technical status report at the meetings. Following submission of the final report, an oral presentation of the study results shall be given to JPL.

3.2.9 Data. -

3.2.9.1 Drawings. - Preliminary design drawings of critical elements and design sketches of the complete antenna system shall be provided. The drawings shall contain sufficient detail design notes and technical assumptions, and calculations, on the drawings or in the final report, to enable JPL to determine if the design requirements can be met by the proposed antenna system. The sketches shall be in sufficient detail to allow visualization of major operational, maintenance, alignment, collimation, and safety problems. The drawings and sketches shall be prepared in accordance with good engineering practices and shall be suitable for the purpose intended.

3.2.9.2 Reports. -

3.2.9.2.1 Informal Status Reports. - Approximately two months after contract go-ahead and one week prior to the formal technical meetings of 3.2.8.2, the Contractor shall submit one reproducible master and twenty print copies of an informal letter type technical status report, to the Jet Propulsion Laboratory. The report shall contain a narrative summary of work performed, including techical status, major accomplishments, problems encountered, and a future work plan.

3.2.9.2.2 Final Report. - One reproducible copy and twenty print copies of a final report shall be submitted to the Jet Propulsion Laboratory at the end of the study program. The report shall meet the minimum requirements of the formal report section of JPL Specification 20017.

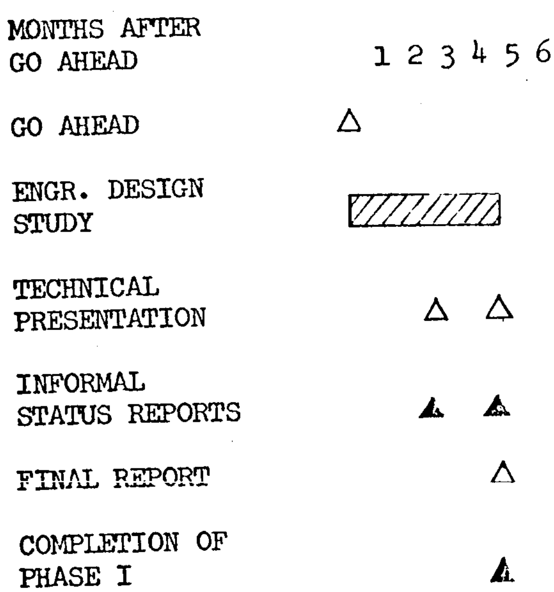
3.2.9.3 Proposal. - One reproducible master and twenty print copies of all information described in paragraph 3.2.4 shall be submitted to the Jet Propulsion Laboratory at the end of the study.

PHASE I

SCHEDULE

ADVANCED ANTENNA SYSTEM

FOR DSIF DESIGN STUDY



APPENDIX B

HYPOTHETICAL CONTROL SYSTEM

A. TYPE OF SYSTEM

1. Let both axes be controlled by an electro-hydraulic servo system to minimize electrical noise and promote smooth low speed operation.

2. Let the azimuth bearing be hydrostatic to support the high thrust, radial and overturning loads with high bearing stiffness but with low breakout friction.

B. LOAD DETERMINATION

1. Since friction will be low, the principal loads are wind and inertia (or kinetic energy).

2. Wind Loads

   (a) The wind forces were determined by using the analysis in "Analytical Design of Linear Feedback Controls" by Newton, Gould and Kaiser, pp. 257. The analysis numbers were scaled up according to antenna size.

   (b) The general expression for wind torque is:

$$U_g = C_w V^2 (t)$$

where U_g = wind torque (lb-ft)

C_w = size coeff. (lb-ft/MPH^2)

V = wind velocity (MPH)

$C_w = .667 \times 10^3$ for 140' antenna but our antenna is 260' dia.

so $$C_w = \frac{D_2^2}{D_1^2} \times .667 \times 10^3 = \left(\frac{260}{140}\right)^2 \times .667 \times 10^3$$

$$C_w = 2.3 \times 10^3 \text{ lb-ft/MPH}^2$$

$$Vi(t) = Vo + V_1 (t)$$

where Vi = instantaneous wind velocity
Vo = steady wind velocity
V_1 = changing wind velocity

APPENDIX B (continued)

whence $U_g(t) = C_w \left[V_o^2 + 2\, V_o\, V_1(t) + V_1^2(t)\right]$

This is the working wind torque equation.

CASE I. V_o = 30 MPH, V_1 = 15 MPH with full acceleration and velocity capabilities.

$$U_g(t) = 2.3 \times 10^3 \left[900 + 900 + 225\right]$$
$$= 4.66 \times 10^6 \text{ lb.-ft.}$$

CASE II. V_o = 45 MPH, V_1 = 15 MPH with 50% of max. capability on velocity and accleration.

$$U_g(t) = 2.3 \times 10^3 \left[2025 + 1350 + 225\right]$$
$$U_g(t) = 10.6 \times 10^6 \text{ lb.-ft.}$$

CASE III. V_o = 60 MPH, V_1 = 10 MPH drive to stow.

$$U_g(t) = 2.3 \times 10^3 \left[3600 + 1200 + 100\right]$$
$$U_g(t) = 11 \times 10^6 \text{ lb.-ft.}$$

3. Acceleration Torque

(a) Antenna Data:

$J_{AZ} = 7.77 \times 10^9$ lb.-ft.^{2}

$J_{EL} = 8.44 \times 10^9$ lb.-ft.^{2}

Weight on both axes = 1.4×10^6 lb.

(b) Since both axes are nearly the same, the worst will be selected.

The full capability acceleration $\ddot{\theta}_L = 0.2^\circ/\text{sec}^2$

The full capability velocity (design goal) $\dot{\theta}_L = 0.5^\circ/\text{sec.}$

APPENDIX B (Continued)

$$\text{Full capability} \quad T_a = \frac{8.44}{32.2} \times 10^9 \times \frac{.2}{57.3}$$

$$T_a = 5.18 \times 10^6 \text{ lb.-ft.}$$

$$\therefore \quad 50\% \text{ capability} \quad T_a = 2.59 \times 10^6 \text{ lb.-ft.}$$

4. Total Torque and Power

CASE I.

$$\begin{array}{ll} & T_a = 5.18 \times 10^6 \text{ lb.-ft.} \\ + & U_g = 4.66 \times 10^6 \\ \hline & T_{TOTAL} = 9.84 \times 10^6 \text{ lb.-ft.} \end{array}$$

CASE II.

$$\begin{array}{l} T_a = 2.59 \times 10^6 \text{ lb.-ft.} \\ U_g = 10.60 \times 10^6 \\ \hline T_{Total} = 13.19 \times 10^6 \text{ lb.-ft.} \end{array}$$

CASE III. $T_{Total} = T_a = 11 \times 10^6$ lb.-ft.

POWER

$$HP \text{ Case 1} = T_{Total} \times \dot{\theta}_{L\,max}$$

$$HP \text{ Case II} = T_{Total\,II} \times \frac{1}{2} \dot{\theta}_{L\,max}$$

$$\therefore \quad HP \text{ Case I} > HP \text{ Case II}$$

$$HP \text{ Req} = \frac{9.84 \times 5.23 \times 10^5}{3.3 \times 10^4} = 156 \ HP/\text{Axis}$$

C. PRIME MOVER REQUIREMENTS

1. To meet the design goals we can summarize the prime mover requirements:

From CASE I	Must be able to drive a load torque of 9.84×10^6 lb.-ft. at 0.5°/sec.
From CASE III	Must produce a stall torque in excess of 11×10^6 lb.-ft.

APPENDIX B (continued)

2. Trial Selection

(a) For each axis use two hydraulic motors driven in parallel and controlled by an electro-hydraulic servo valve.

Let the highest load torque be sustained with a pressure difference of 2000 psi across the motors.

Let the pump pressure P_S = 2500 psi. This allows a margin of at least 500 psi for line losses and uncertainties.

(b) Imposing the conditions mentioned

$$\frac{T_s}{G} = \frac{P_m \, 2D_m}{24}$$

where T_s = 11×10^6 lb.-ft.

G = gear ratio (motor speed/load speed)

P_m = 2000 psi

D_m = displacement of one hyd. motor (in.^{3}/rev.)

also $\dot{\theta}_{L max}$ = $.5^\circ$/sec. = .0833 RPM

so $G = \dfrac{N}{.0833}$

where N = max. recommended motor speed (RPM)

combining the above two expressions

$$D_m N = 17.3 \times 10^3$$

(c) We will now tabulate a series of commercial hydraulic motors to determine those acceptable.

APPENDIX B (continued)

VICKERS INDUSTRIAL MOTORS

Motor No.	Max. Speed RPM (N)	Displ. in ^{3}/rev. (D_m)	D_mN x 10^{-3}	Satisfactory?	Cost
1	900	38.33	34.5	Yes	$5295
2	1100	30.57	34.7	Yes	
3	1000	23.71	23.71	Yes	$3295
4	1200	18.91	22.7	Yes	
5	1200	14.96	18	Yes	$3050
6	1500	11.93	18	Yes	
7	1300	9.48	12.3	No	
8	1650	7.56	12.65	No	

(d) Six motors are satisfactory but the smaller two are the least expensive. The choice will then be narrowed to these two; although a more careful cost consideration would be made considering the other control elements in a final analysis.

Since both of the smaller motors have the same D_mN product we will choose the one with the smallest displacement since this motor has a universal joint at 23 degrees rather than 30 degrees. This choice is based on reliability since the universal joint is the weakest member in the motor. The choice then is Motor No. 6.

The gear ratio is

$$G = \frac{N}{.0833} = \frac{1500}{.0833} = 18000:1$$

APPENDIX B (continued)

D. REFLECTED LOAD INERTIA

$$J_{Ref} = \frac{J_L}{N^2} = \frac{2.62 \times 10^8}{(1.8)^2 \times 10^8} = .81 \text{ slug ft}^2$$

$$J_{Ref} = 9.75 \text{ lb.in.sec.}^2$$

The motor inertia, $J_m = .246$ lb.in.sec.^{2}

In this case, the gear train, rather than the load, would probably contribute the largest inertia reflected to the motor shaft.

E. VALVE - MOTOR - LOAD CORNER FREQUENCY

Let the total reflected inertia = 20 lb-in.sec^2

Let the volume of oil under compression (2 x vol. in one line between servo valve and a motor + 1/2 contained oil in one motor x 2 motors) = 200 in^3.

Let the effective oil bulk modulus, = 100,000 psi so that mechanical elastance can be included.

Whence $$\omega_n = \frac{2 \beta \, d_m^2}{J_{Ref} \, V_c} = \frac{2 \times 10^5 \times 3.8 \times 3.8}{2 \times 10 \times 2 \times 10^2}$$

$$\omega_n = 27 \text{ rad./sec.} = 4.28 \text{ cps}$$

assume $\delta = 0.6$

F. SYSTEM SELECTION

1. For a Type I System

The design goals are:

(a) Closed-loop bandwidth $\omega_b \leq .01$ cps

* (b) $K_v = 150$ sec.$^{-1}$

APPENDIX B (continued)

(c) $\delta = 0.7$

* If pointing accuracy of RF axis = $\pm$ 0.01° peak at design goal speed of 0.5°/sec.

for one axis $\varepsilon_{ss} \leq \frac{.01}{2} = .007°$

so $K_v = \frac{.5}{.007} = 71 \text{ sec}^{-1}$

Let $K_v = 150 \text{ sec}^{-1}$

2. A type one system was then designed with $\omega_b = .01$ cps, $K_v = 150 \text{ sec}^{-1}$ $M_p = 1.3$ db

   but it contained two large time constants:

   $T_1 = 5000$ sec.

   $T_2 = 500$ sec.

3. Next a Type I system was designed for the maximum allowable bandwidth of $\omega_b = 0.2$ cps. and a max. antenna rate of .25°/sec. This system has realizable time constants and a velocity constant of 70 sec^{-1}. A Bode diagram of the system open-loop frequency response is shown in Figure IIIC-4.

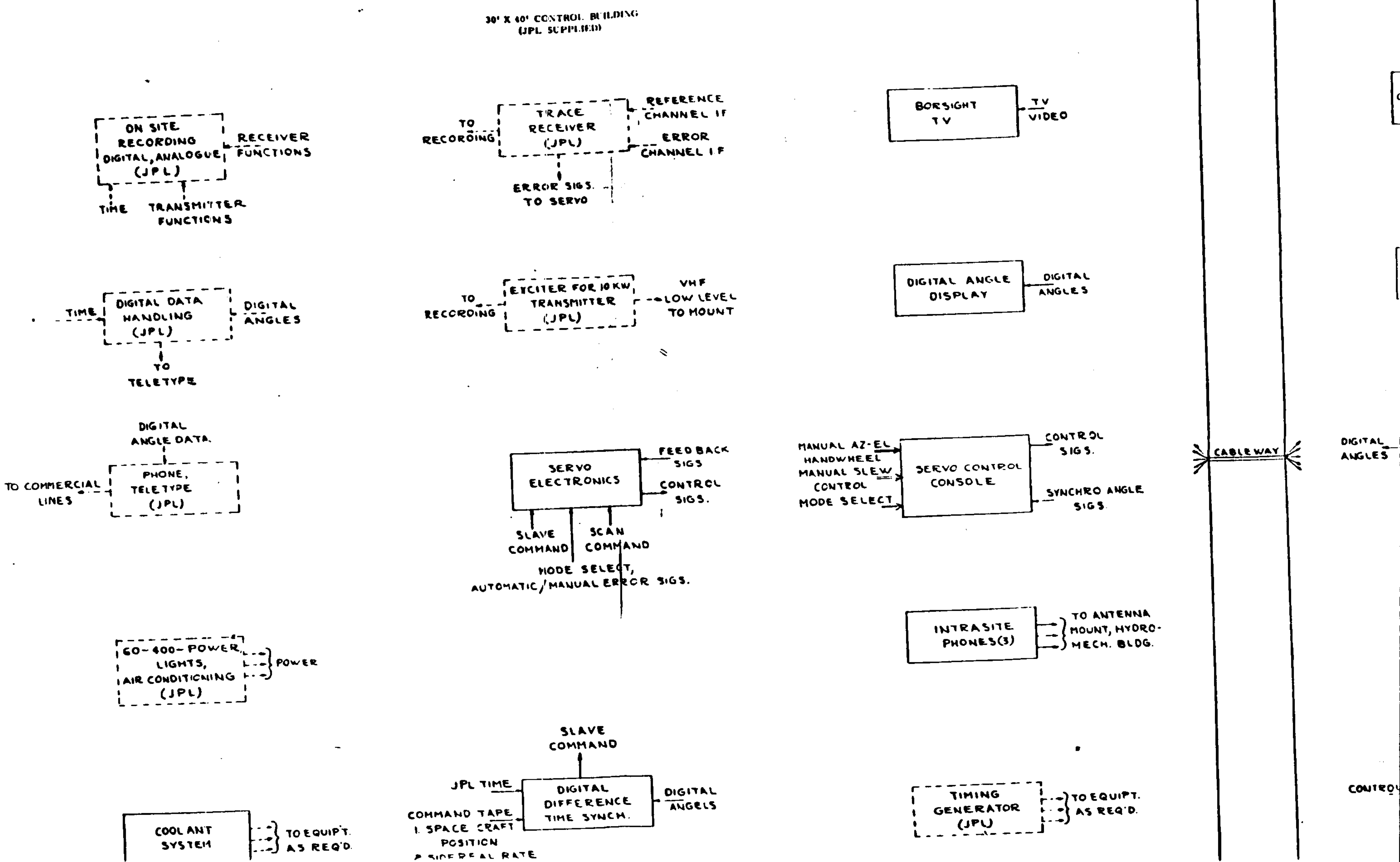
4. A Type II system was also designed for both extremes of the bandwidth adjustment (See Figure IIIC-3.)

G. CONCLUSION

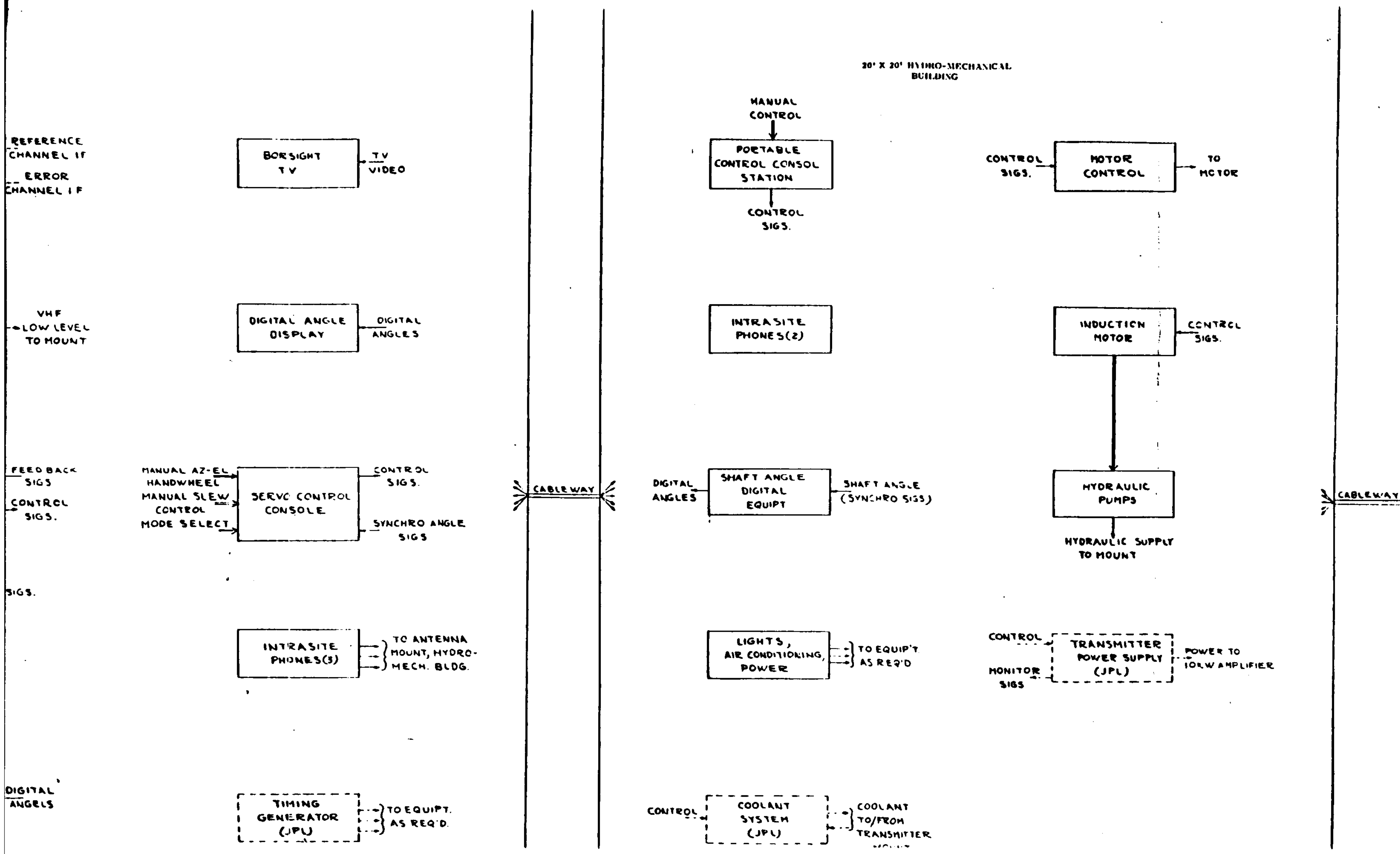
A Type I control system can be designed to meet the requirements for pointing accuracy at antenna rates up to .25°/sec. while simultaneously satisfying the maximum bandwidth requirement of 0.2 cycles/second. This system employs familiar design techniques and utilizes conventional hardware.

APPENDIX B (continued)

When bandwidth is reduced to the minimum specified (.01 cps) a reduction in system gain to a very low value is necessary unless (1) time constants are introduced which are very hard to physically realize or (2) other sophisticated control techniques are used.



30' X 40' CONTROL BUILDING
(JPL SUPPLIED)
ON SITE RECORDING DIGITAL, ANALOGUE (JPL)
RECEIVER FUNCTIONS
TIME
TRANSMITTER FUNCTIONS
TRACE RECEIVER (JPL)
TO RECORDING
REFERENCE CHANNEL IF
ERROR CHANNEL IF
ERROR SIGS. TO SERVO
BORSIGHT TV
TV VIDEO
DIGITAL DATA HANDLING (JPL)
TIME
DIGITAL ANGLES
TO TELETYPE
EXCITER FOR 10 KW TRANSMITTER (JPL)
TO RECORDING
VHF LOW LEVEL TO MOUNT
DIGITAL ANGLE DISPLAY
DIGITAL ANGLES
DIGITAL ANGLE DATA
PHONE, TELETYPE (JPL)
TO COMMERCIAL LINES
SERVO ELECTRONICS
FEED BACK SIGS
CONTROL SIGS.
SLAVE COMMAND
SCAN COMMAND
MODE SELECT, AUTOMATIC/MANUAL ERROR SIGS.
SERVO CONTROL CONSOLE
MANUAL AZ-EL HANDWHEEL
MANUAL SLEW CONTROL
MODE SELECT
CONTROL SIGS.
SYNCHRO ANGLE SIGS.
CABLEWAY
DIGITAL ANGLES
60-400- POWER, LIGHTS, AIR CONDITIONING (JPL)
POWER
INTRASITE PHONES(3)
TO ANTENNA MOUNT, HYDRO-MECH. BLDG.
SLAVE COMMAND
DIGITAL DIFFERENCE TIME SYNCH.
JPL TIME
COMMAND TAPE
1. SPACE CRAFT POSITION
DIGITAL ANGELS
COOLANT SYSTEM
TO EQUIP'T. AS REQ'D.
TIMING GENERATOR (JPL)
TO EQUIPT. AS REQ'D.
CONTROL



REFERENCE CHANNEL IF
ERROR CHANNEL IF
VHF LOW LEVEL TO MOUNT
FEED BACK SIGS
CONTROL SIGS.
SIGS.
DIGITAL ANGELS
BORSIGHT TV
TV VIDEO
DIGITAL ANGLE DISPLAY
DIGITAL ANGLES
MANUAL AZ-EL HANDWHEEL
MANUAL SLEW CONTROL
MODE SELECT
SERVO CONTROL CONSOLE
CONTROL SIGS.
SYNCHRO ANGLE SIGS
INTRASITE PHONES(3)
TO ANTENNA MOUNT, HYDRO-MECH. BLDG.
TIMING GENERATOR (JPL)
TO EQUIPT. AS REQ'D.
CABLEWAY
20' X 20' HYDRO-MECHANICAL BUILDING
MANUAL CONTROL
PORTABLE CONTROL CONSOL STATION
CONTROL SIGS.
INTRASITE PHONES(2)
DIGITAL ANGLES
SHAFT ANGLE DIGITAL EQUIPT
SHAFT ANGLE (SYNCHRO SIGS)
LIGHTS, AIR CONDITIONING, POWER
TO EQUIP'T AS REQ'D
CONTROL
COOLANT SYSTEM (JPL)
COOLANT TO/FROM TRANSMITTER
CONTROL SIGS.
MOTOR CONTROL
TO MOTOR
INDUCTION MOTOR
CONTROL SIGS.
HYDRAULIC PUMPS
HYDRAULIC SUPPLY TO MOUNT
CONTROL
MONITOR SIGS
TRANSMITTER POWER SUPPLY (JPL)
POWER TO 10KW AMPLIFIER
CABLEWAY

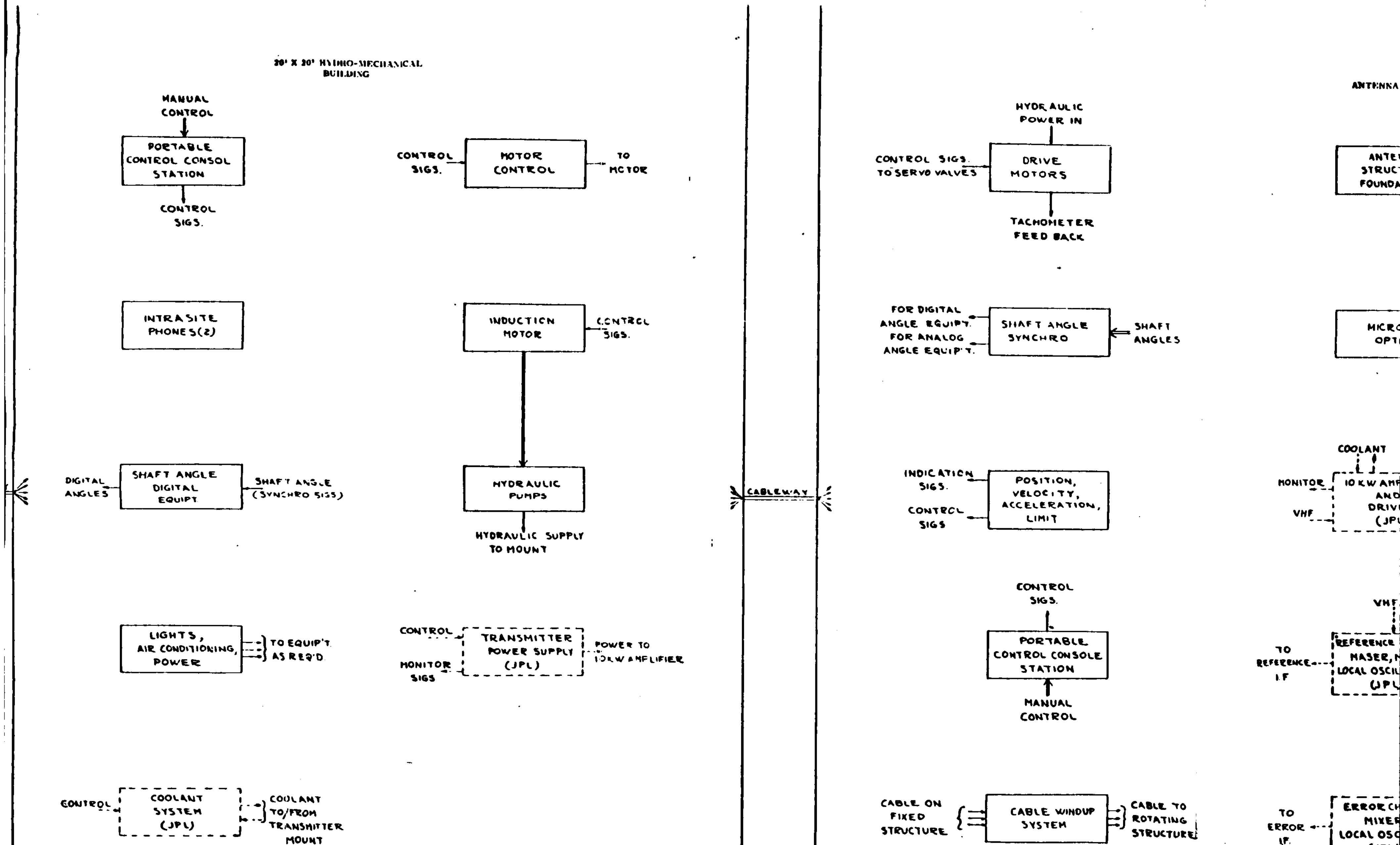
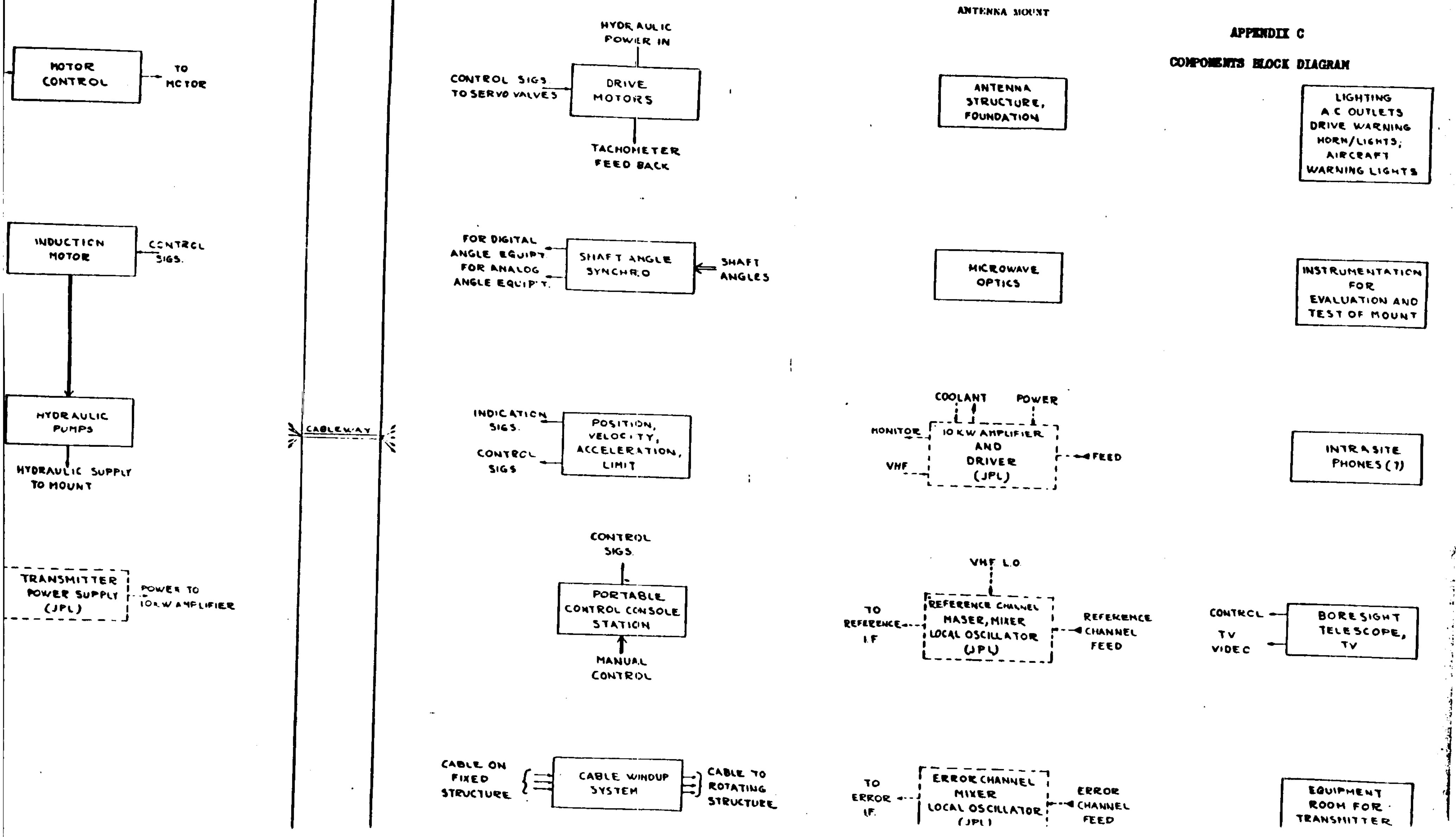

20' X 20' HYDRO-MECHANICAL BUILDING
MANUAL CONTROL
PORTABLE CONTROL CONSOL STATION
CONTROL SIGS.
INTRASITE PHONES(2)
DIGITAL ANGLES
SHAFT ANGLE DIGITAL EQUIPT
SHAFT ANGLE (SYNCHRO SIGS)
LIGHTS, AIR CONDITIONING, POWER
TO EQUIP'T AS REQ'D
CONTROL
COOLANT SYSTEM (JPL)
COOLANT TO/FROM TRANSMITTER MOUNT
CONTROL SIGS.
MOTOR CONTROL
TO MOTOR
INDUCTION MOTOR
CONTROL SIGS.
HYDRAULIC PUMPS
HYDRAULIC SUPPLY TO MOUNT
CONTROL
MONITOR SIGS
TRANSMITTER POWER SUPPLY (JPL)
POWER TO 10KW AMPLIFIER
CABLEWAY
HYDRAULIC POWER IN
CONTROL SIGS. TO SERVO VALVES
DRIVE MOTORS
TACHOMETER FEED BACK
FOR DIGITAL ANGLE EQUIPT.
FOR ANALOG ANGLE EQUIP'T.
SHAFT ANGLE SYNCHRO
SHAFT ANGLES
INDICATION SIGS.
CONTROL SIGS
POSITION, VELOCITY, ACCELERATION, LIMIT
CONTROL SIGS.
PORTABLE CONTROL CONSOLE STATION
MANUAL CONTROL
CABLE ON FIXED STRUCTURE
CABLE WINDUP SYSTEM
CABLE TO ROTATING STRUCTURE
ANTENNA
COOLANT
MONITOR
VHF
VHF
TO REFERENCE I.F.
TO ERROR I.F.

Figure 4

APPENDIX C

COMPONENTS BLOCK DIAGRAM

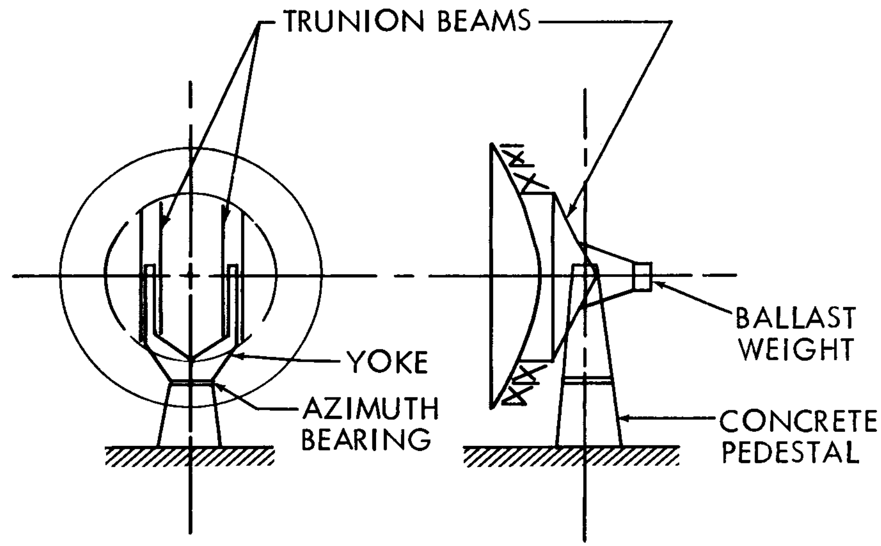


APPENDIX D

COMPARISON OF MOUNTING CONFIGURATIONS

(FIGURE III B-1)

ITEM & COMMENTS	VERSION "A" BASIC DIM'NS	WEIGHT LB
BASIC ANTENNA SYSTEM – HYP., HYP. SUPPORTS, PARA, BACK-UP STRUCTURE	270 FEET DIAM SYSTEM	642,000
TRUNNION BEAMS - SUCH STRUCTURE AS IS REQUIRED TO TRANSFER SYSTEM LOADS TO EL BEARINGS	124 FEET 4 BEAMS	183,000
COUNTERBALANCE WEIGHTS & NECESSARY SUPPORTING STRUCTURE (STEEL WEIGHTS UNLESS STATED)		355,000
ELEVATION DRIVE PROVISIONS - RACKS & NECESSARY SUPPORTING STRUCTURE	22.5 FEET RADIUS	36,000
ELEVATION - AZIMUTH MOUNT - INCLUDING CROSSTIES & PINTLE BEARINGS WHERE APPLICABLE	YOKE 125 FT ACROSS, 112 FT HIGH	1,125,000
CONCRETE PEDESTAL BASE - WHERE APPLICABLE	68 FT HIGH 65 FT DIAM AT BASE	NOT OF INTEREST
RELATIVE COST FACTOR	1.8	
ANTICIPATED LOWEST NATURAL FREQUENCY, COMPONENT & MODE	2.4 CYCLES/SECOND YOKE IS CRITICAL IN DIFFERENTIAL BENDING AND CANTILEVER MODES	
APPROXIMATE MOMENTS OF INERTIA – ELEV. & AZIMUTH ($LB - FT^2$)	BASIC SYSTEM RF AXIS 4559×10^6; EL AXIS 4980×10^6 EL - AZ MOUNT (AZIMUTH AXIS ONLY) 6460×10^6	
CONCLUDING REMARKS	NOT SUFFICIENTLY STIFF. ALREADY HIGH COST MAKES PROHIBITIVELY HIGH COST WHEN STIFFENED UP	
"GROUND RULES" MET.	d, e, f, g (WITH DETAIL DESIGN) h, j. (WITH DETAIL DESIGN)	

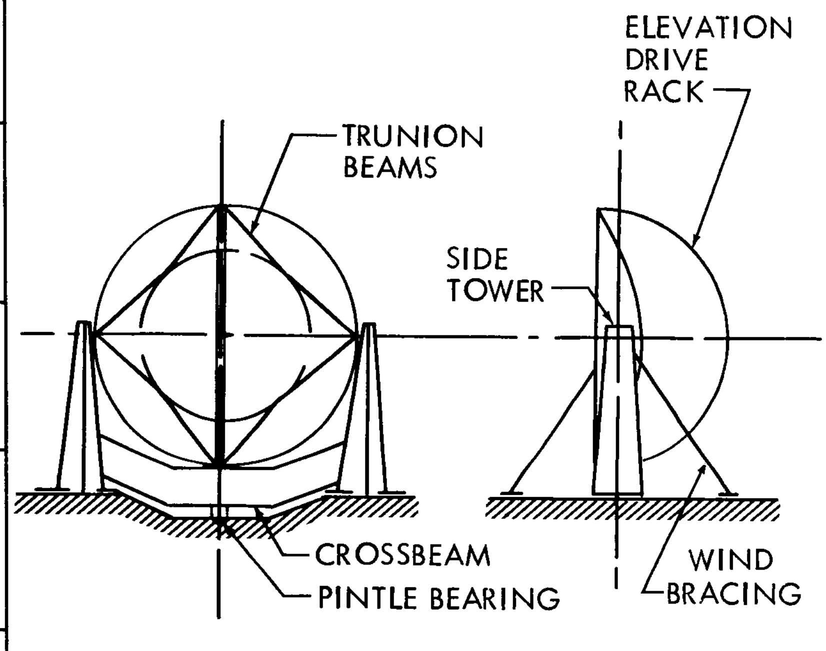


VERSION "A"

APPENDIX D.

COMPARISON OF MOUNTING CONFIGURATIONS
(FIGURE III B-1) CONTINUED

ITEM & COMMENTS	VERSION BASIC DIM'NS	WEIGHT LB
BASIC ANTENNA SYSTEM - HYP., HYP. SUPPORTS, PARA, BACK-UP STRUCTURE	270 FEET DIAM SYSTEM	642,000
TRUNNION BEAMS - SUCH STRUCTURE AS IS REQUIRED TO TRANSFER SYSTEM LOADS TO EL BEARINGS	200 FEET 4 BEAMS	293,000
COUNTERBALANCE WEIGHTS & NECESSARY SUPPORTING STRUCTURE (STEEL WEIGHTS UNLESS STATED)	NONE REQUIRED	NONE REQUIRED
ELEVATION DRIVE PROVISIONS - RACKS & NECESSARY SUPPORTING STRUCTURE	MIXED STEEL & ALUM	37,000 225,000
ELEVATION-AZIMUTH MOUNT - INCLUDING CROSSTIES & PINTLE BEARINGS WHERE APPLICABLE	TOWERS 142 FT HIGH 270 FT APART	1,125,000
CONCRETE PEDESTAL BASE - WHERE APPLICABLE	NONE REQUIRED	NONE REQUIRED
RELATIVE COST FACTOR	1.5	
ANTICIPATED LOWEST NATURAL FREQUENCY, COMPONENT & MODE	3.0 + CYCLES/SECOND TOWERS ARE CRITICAL IN DIFFERENTIAL BENDING AND CANTILEVER MODES	
APPROXIMATE MOMENTS OF INERTIA - ELEV. & AZIMUTH ($LB - FT^2$)	BASIC SYSTEM RF AXIS 4559×10^6; EL AXIS 4720×10^6 EL - AZ MOUNT (AZIMUTH AXIS ONLY) 28940×10^6	
CONCLUDING REMARKS	VERY HIGH AZIMUTH MOMENT OF INERTIA. COSTS OF BASIC SYSTEM TRUNNION BEAMS ARE HIGH	
"GROUND RULES" MET.	d, e, f, g (WITH DETAIL DESIGN) h, j.	



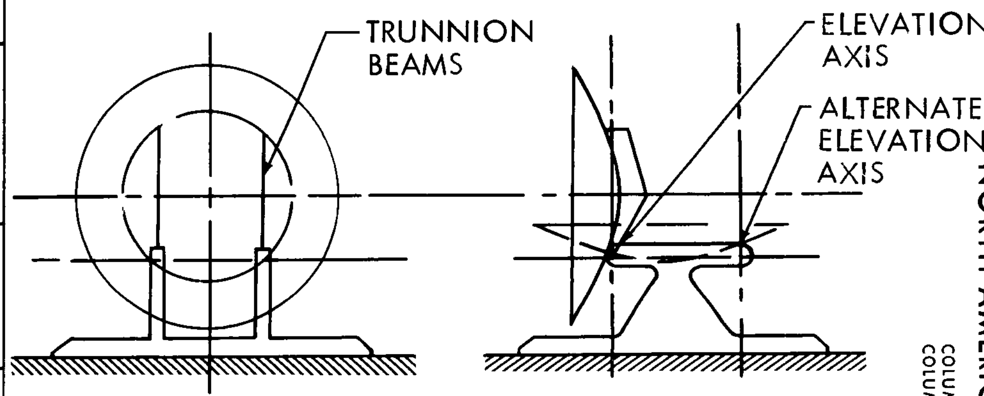
VERSION "B"

APPENDIX D.

COMPARISON OF MOUNTING CONFIGURATIONS

(FIGURE III B-1) CONTINUED

ITEMS & COMMENTS	VERSION "C" BASIC DIM'NS	WEIGHT - LBS
BASIC ANTENNA SYSTEM - HYP., HYP. SUPPORTS, PARA, BACK-UP STRUCTURE	270 FEET DIA DIAM SYSTEM	642,000
TRUNNION BEAMS - SUCH STRUCTURE AS IS REQUIRED TO TRANSFER SYSTEM LOADS TO EL BEARINGS	DEPENDS UPON POWER & DRIVE SYSTEM CHOSEN ESTIMATED AT	183,000
COUNTERBALANCE WEIGHTS & NECESSARY SUPPORTING STRUCTURE (STEEL WEIGHTS UNLESS STATED)	DEPENDS UPON POWER & DRIVE SYSTEM CHOSEN. NOT INCLUDED IN ESTIMATES	
ELEVATION DRIVE PROVISIONS - RACKS & NECESSARY SUPPORTING STRUCTURE	DEPENDS UPON POWER & DRIVE SYSTEM CHOSEN: ESTIMATED AT ALUM STEEL	 56,000 225,000
ELEVATION-AZIMUTH MOUNT - INCLUDING CROSSTIES & PINTLE BEARINGS WHERE APPLICABLE	70 FT HIGH 125 FT ACROSS ARMS	900,000
CONCRETE PEDESTAL BASE - WHERE APPLICABLE	NOT OF INTEREST	
RELATIVE COST FACTOR	1.6	
ANTICIPATED LOWEST NATURAL FREQUENCY COMPONENT & MODE	2.7 CYCLES/SECOND MOUNT ARMS ARE CRITICAL IN CANTILEVER MODE	
APPROXIMATE MOMENTS OF INERTIA - ELEV. & AZIMUTH ($LB - FT^2$)	BASIC SYSTEM RF AXIS 4559 X 10^6; EL AXIS 5230 X 10^6 EL-AZ MOUNT (AZIMUTH AXIS ONLY) 8,967 X 10^6	
CONCLUDING REMARKS	INVOLVES TRAVELLING CENTER OF MASS, POOR DISTRIBUTION OF POWER, IS INSUFFICIENTLY STIFF	
"GROUND RULES" MET.	d (POOR DESIGN ALL ROUND)	

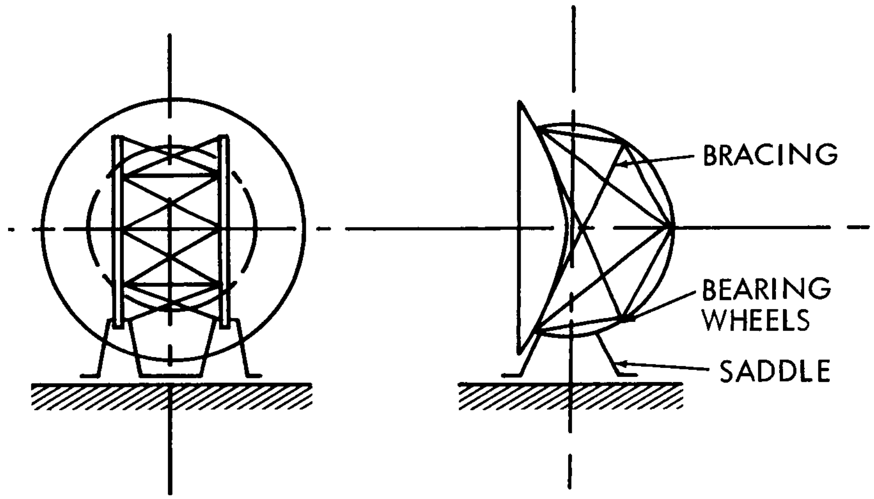


VERSION "C"

APPENDIX D.

COMPARISON OF MOUNTING CONFIGURATIONS
(FIGURE III B-1) CONTINUED

	VERSION "D" BASIC DIM'NS	WEIGHT - LB
BASIC ANTENNA SYSTEM - HYP., HYP. SUPPORTS, PARA, BACK-UP STRUCTURE	270 FEET DIAM SYSTEM	642,000
TRUNNION BEAMS - SUCH STRUCTURE AS IS REQUIRED TO TRANSFER SYSTEM LOADS TO EL BEARINGS	NONE REQUIRED	
COUNTERBALANCE WEIGHTS & NECESSARY SUPPORTING STRUCTURE (STEEL WEIGHTS UNLESS STATED)	NONE REQUIRED	
ELEVATION DRIVE PROVISIONS - RACKS & NECESSARY SUPPORTING STRUCTURE	158 FEET DIAM X 2 FEET WIDE	1,547,000
ELEVATION - AZIMUTH MOUNT - INCLUDING CROSSTIES & PINTLE BEARINGS WHERE APPLICABLE	70 FT HIGH SADDLES 125 FT ACROSS	844,000
CONCRETE PEDESTAL BASE - WHERE APPLICABLE	NOT OF INTEREST	
RELATIVE COST FACTOR	1.5	
ANTICIPATED LOWEST NATURAL FREQUENCY, COMPONENT & MODE	4+ CYCLES/SECOND BRACING IN "FERRIS WHEELS" ARE CRITICAL IN VIBRATION AS A VIOLIN STRING	
APPROXIMATE MOMENTS OF INERTIA - ELEV. & AZIMUTH ($LB - FT^2$)	BASIC SYSTEM RF AXIS 4559 X 10^6, EL AXIS 4980 X 10^6 EL-AZ MOUNT (AZIMUTH AXIS ONLY) 8,403 X 10^6	
CONCLUDING REMARKS	HEAVIEST, PRESENTS MANY BEARING & ENVIRONMENTAL LOAD PROBLEMS	
"GROUND RULES" MET.	d, e, f, g (WITH DETAIL DESIGN) h, j	



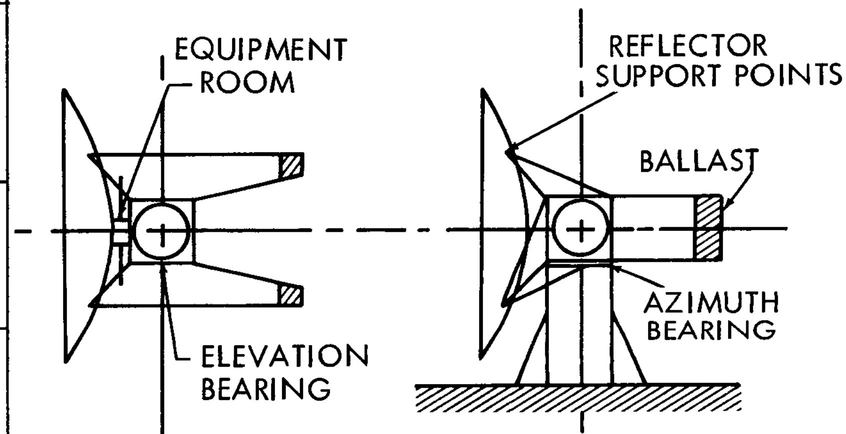
VERSION "D"

APPENDIX D.

COMPARISON OF MOUNTING CONFIGURATIONS

(FIGURE III B-1) CONTINUED

ITEM & COMMENTS	VERSION E BASIC DIM'NS	WEIGHT LB
BASIC ANTENNA SYSTEM - HYP., HYP. SUPPORTS, PARA, BACK-UP STRUCTURE	270 FEET DIAM SYSTEM	642,000
TRUNNION BEAMS - SUCH STRUCTURE AS IS REQUIRED TO TRANSFER SYSTEM LOADS TO EL BEARINGS	NONE REQUIRED	NONE REQUIRED
COUNTERBALANCE WEIGHTS & NECESSARY SUPPORTING STRUCTURE (STEEL WEIGHTS UNLESS STATED)	CONCRETE BLOCKS 120 FT ARM	321,000 450,000
ELEVATION DRIVE PROVISIONS - RACKS & NECESSARY SUPPORTING STRUCTURE	50 FT CUBE OF STRUCTURE	15,000
ELEVATION-AZIMUTH MOUNT - INCLUDING CROSSTIES & PINTLE BEARINGS WHERE APPLICABLE	INCLUDED IN ABOVE ITEMS	
CONCRETE PEDESTAL BASE - WHERE APPLICABLE	120 FT HIGH 2 FT THICK 45' DIA	NOT OF INTEREST
RELATIVE COST FACTOR	1.0	
ANTICIPATED LOWEST NATURAL FREQUENCY, COMPONENT & MODE	5 + CYCLES/SECOND BALLAST ARMS AS CANTILEVERS COULD BE TAILORED TO SUIT FROM 6 CPS – 3 CPS WITH EASE	
APPROXIMATE MOMENTS OF INERTIA - ELEV. & AZIMUTH (LB - FT^2)	BASIC SYSTEM RF AXIS 4559×10^6; EL AXIS 5230×10^6 EL - AZ MOUNT AZIMUTH AXIS (WORST) 3212×10^6 ELEVATION AXIS (CONST) 3212×10^6	
CONCLUDING REMARKS	LIGHTEST, STIFFEST, CHEAPEST, LEAST COMPLICATED. TOWER GIVES BONUS OF HOUSING SPACE	
"GROUND RULES" MET.	ALL	



PLAN VIEW

SIDE ELEVATION

VERSION "E"

VARIATION IN EL-AXIS TERM CAUSED BY OFFSET OF BASIC SYSTEM FROM ELEVATION AXIS

APPENDIX E

EFFECT OF APERTURE ILLUMINATION ON GAIN

Antenna gain depends on the distribution of energy across the aperture of the antenna. Since the antenna of concern here is very large in terms of wavelengths, the Fourier integral form for the far field is applicable. The maximum gain of a narrow beam antenna is given by the expression,

$$G_M = \frac{4\pi}{\lambda^2} \frac{\left| \iint_A F(\xi,\eta)\, d\xi\, d\eta \right|^2}{\iint_A |F(\xi,\eta)|^2 d\xi\, d\eta}$$

where

G_M = maximum gain relative to an isotropic radiator

λ = wavelength

ξ, η = coordinates of points in the antenna aperture, A

$F(\xi,\eta)$ = aperture illumination function, amplitude and phase

For circular apertures, the origin of the coordinate system may be taken to be the center of the aperture with points in the aperture described by a radius, ρ , and an angle, ϕ'. The gain equation then becomes

$$G_M = \frac{4\pi}{\lambda^2} \frac{\left| \int_0^{2\pi}\int_0^{a} F(\rho,\phi')\rho\, d\rho\, d\phi' \right|^2}{\int_0^{2\pi}\int_0^{a} |F(\rho,\phi')|^2 \rho\, d\rho\, d\phi'}$$

where

a = radius of aperture

Only circularly symmetric distributions, independent of ϕ', are considered here for illustrative purposes. When radial distance is normalized to the radius of the aperture, the gain is given by the following equation:

$$G_M = \frac{8\pi A}{\lambda^2} \frac{\left|\int_0^1 f(r) r\, dr\right|^2}{\int_0^1 |f(r)|^2 r\, dr}$$

where

A = area of aperture

r = normalized radial distance, ρ/a

Uniform illumination, $f(r) = 1$, produces a gain of $4\pi A/\lambda^2$. When the illumination is tapered, such as to obtain lower sidelobe levels, the gain is less than that for uniform illumination. Two cases are calculated below: first, a tapered illumination without blocking, and second, the same taper with blocking to show the amount of gain reduction expected due to blocking. The taper to be used for the proposed antenna does not correspond exactly to that used here but will probably correspond more nearly to a Taylor distribution. Taper will be controlled by the eccentricity of the hyperboloidal minor reflector. The following calculations are made to estimate the order of magnitude of gain reduction expected due to blocking.

Case 1. Tapered Illumination - No Blocking

$$f(r) = 1 - r^2$$

$$G_M = \frac{8\pi A}{\lambda^2} \frac{\left|\int_0^1 [r - r^3]\, dr\right|^2}{\int_0^1 [1 - 2r^2 + r^4] r\, dr}$$

$$= \frac{8\pi A}{\lambda^2} \frac{1/16}{1/6}$$

$$= \frac{3\pi A}{\lambda^2} = 0.75 \frac{4\pi A}{\lambda^2}$$

Thus, tapering the illumination in this manner reduces the gain by 1.25 db from that obtainable with uniform illumination.

Case 2. Tapered Illumination - With Blocking

$$f(r) = \begin{cases} 0 & (0 \leq r < \delta) \\ 1 - r^2 & (\delta < r \leq 1) \end{cases}$$

$$G_M = \frac{8\pi A}{\lambda^2} \frac{\left| \int_\delta^1 [r - r^3] dr \right|^2}{\int_\delta^1 [r - 2r^3 + r^5] dr}$$

$$= \frac{8\pi A}{\lambda^2} \frac{1/16 \, [1 - 2\delta^2 + \delta^4]^2}{1/6 \, [1 - 3\delta^2 + 3\delta^4 - \delta^6]}$$

$$= \frac{3\pi A}{\lambda^2} \frac{(1-\delta^2)^4}{(1-\delta^2)^3} = (1 - \delta^2) \frac{3\pi A}{\lambda^2}$$

For blocking by an hyperboloid minor reflector of diameter, d, the gain reduction factor is $1 - \delta^2 = 1 - (d/2a)^2 = 1 - (A_h/A)$, where A_h is the area of the hyperboloid reflector. Note that $(1 - \delta^2)A = A - A_h$, the unblocked area of the aperture.

For a minor reflector diameter of 30' and a major reflector diameter of 270', the reduction in gain due to blocking is 0.06 db.

APPENDIX F

EFFECT OF DEFLECTIONS ON GAIN

Deflections of the reflecting surfaces from their ideal shapes result in phase errors in the aperture illumination. Amplitude is also affected by changes in slope of the surfaces which tend to cause a redistribution of energy, but phase errors are the more important in degrading performance. Generally, two types of deflections may be considered, those which are random and those which are "systematic". The random type of deflections, due to manufacturing tolerances and thermal gradients, is expected to be of such small magnitude that they have a negligible effect on gain. Maximum random deflections of the order of 0.03 inches are estimated for the major reflector. If it is assumed that the error in microwave path length due to this maximum error corresponds to the $3\bar{\epsilon}$ value and is doubled to account for an equal contribution from the minor reflector, the degradation in gain is of the order of 0.01 db. This calculation is based on the use of Ruze's formula, $\exp\left[-(4\pi\bar{\epsilon}/\lambda)^2\right]$.

Reduction in gain due to systematic-type errors is not negligible and is described here. The type of deflections considered are those that cover relatively large portions of the reflector surfaces resulting in a small number of large area deflections. When the deflections are odd about the center of the reflector, i.e., forward deflections on one side of center and backward deflections on the other side, the major effect is to shift the main beam off center. Deflections even about the center or all in the same direction tend to reduce gain and change the sidelobe levels. The calculation of gain reduction due to the anticipated form of deflections even about the center is shown below.

As in Appendix E, the equation for gain of a circular antenna with circular symmetric aperture distribution is as follows:

$$G_M = \frac{8\pi A}{\lambda^2} \frac{\left|\int_0^1 f(r)\,r\,dr\right|^2}{\int_0^1 |f(r)|^2\,r\,dr}$$

where

A = aperture area

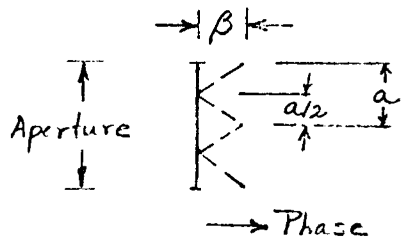
λ = wavelength

r = normalized radial distance in the aperture

The effects of amplitude distributions have been treated in Appendix E. Since the primary effect of reflector deflections is on phase, a fixed amplitude distribution is chosen with the phase distribution depending on the form of the deflections. For simplicity a uniform amplitude distribution is used in these preliminary calculations.

The form of structure proposed for the antenna is such that the large reflector face is held rigidly at points on a circular ring about the center. For purposes of calculation it may be assumed that the radius of the ring is one-half the radius of the antenna. Consequently, the maximum deflections occur in the central region of the reflector and near the outer edge. Greatest degradation to gain occurs when a strong wind is normally incident on the antenna, along its axis. Dead weight also causes a degradation in gain when the antenna is pointing nearly horizontal as well as causing a pointing error.

The assumed phase distribution due to deflections is shown in the following sketch:



Analytically, the aperture distribution is

$$f(r) = \begin{cases} e^{-j\beta(1-2r)} & \left(0 \leq r < \frac{1}{2}\right) \\ e^{-j\beta(2r-1)} & \left(\frac{1}{2} < r \leq 1\right) \end{cases}$$

where

β = phase at center and edge of aperture with respect to that corresponding to rigid ring support

The gain equation becomes

$$G_M = \frac{8\pi A}{\lambda^2} \frac{\left| \int_0^{1/2} e^{-j\beta(1-2r)} r\,dr + \int_{1/2}^{1} e^{-j\beta(2r-1)} r\,dr \right|^2}{\int_0^1 r\,dr}$$

$$= \frac{16\pi A}{\lambda^2} \left| e^{-j\beta} \int_0^{1/2} e^{j2\beta r} r\,dr + e^{j\beta} \int_{1/2}^{1} e^{-j2\beta r} r\,dr \right|^2$$

$$= \left[\frac{\sin(\beta/2)}{(\beta/2)} \right]^2 \frac{4\pi A}{\lambda^2}$$

Thus for the type of deflections expected with the proposed design, the gain reduction factor is the $\sin^2 x/x^2$ term in the above equation.

The phase deviations must now be related to the deflections of the reflectors. When a ray is incident on a reflecting surface from a direction perpendicular to the surface, the reflected ray undergoes a change in path length equal to twice the amount of the deflection of the surface. For non-normal incident rays the change in path length is less than this amount. However, for simplicity, a factor of two will be used to change deflection amounts to path length differences. Another factor of two is used to account for the fact that two reflectors are used in the Cassegrain system. Although the deflections of the minor hyperboloid reflector are much smaller than those of the large paraboloid, their contribution to path length differences are significant due to the magnification effect.

Wind load causes the greatest reduction in gain when the wind is normally incident on the antenna, along the axis of the antenna. Dead weight tends to cause deflections odd about the center, but there is an even component which degrades gain. It is assumed here that the even component of deflection is one-half of the total deflection expected due to dead weight. Note that the maximum reduction in gain occurs when the antenna is pointing horizontally and in the direction of the wind. In general, the gain is not reduced this much. The average reduction in gain is assumed to be that value corresponding to deflections of one-half those expected in the worst case.

Expected values of deflections are functions of the diameter of the antenna. As an example of the calculation, assume a 270-foot diameter antenna. A 30 mph wind normally incident on the antenna would cause a maximum deflection of 0.171 inch. Dead weight with the antenna pointing horizontally would cause a maximum deflection of 0.274 inch, with one-half this value being the even contribution. Adding and doubling to account for the minor reflector deflection, a total deflection of 0.616 inch and a path length difference of 1.232 inches results. At a receiving wavelength of 5.15 inches, this difference is 0.24 wavelengths or a phase shift of 1.51 radians. Then sin(0.755)/0.755 is 0.907, which squared equals 0.824 or -0.84 db. This gain reduction is for the worst case of the wind normally incident on the antenna. In the average case, the gain change is -0.22 db, calculated using one-half the deflection.

Gain reduction values for other size antennas are shown in a figure elsewhere in this proposal.

APPENDIX G

SIDELOBE DEPENDENCE ON APERTURE ILLUMINATION AND DEFLECTIONS

Sidelobe levels are considerably influenced by the aperture distribution, both amplitude and phase. Amplitude is determined by the design taper used to achieve low sidelobes and by the blocking caused by the Cassegrain minor reflector. Phase deviations are caused by deflections of the reflector surfaces. In order to achieve low noise temperature and minimum solar noise contribution, the sidelobe levels must be reduced to a minimum. Unfortunately, calculation of sidelobe levels for complicated distributions is very difficult analytically. During the Phase I study, numerical integration techniques will be employed as necessary to estimate the results expected. A simple amplitude distribution case is shown below.

First of all, the field strength pattern for a circular aperture with circularly symmetric illumination is given by the equation,

$$g(u) = 2\pi a^2 \int_0^1 r f(r) J_0(ur)\, dr$$

where

$u = (2\pi a/\lambda) \sin \theta$

a = radius of antenna

λ = wavelength

θ = polar angle from antenna axis

$g(u)$ = relative field strength (power is square of g)

r = relative radial distance in the antenna aperture

$f(r)$ = aperture illumination function

J_0 = Bessel function of order zero

For uniform illumination, the pattern function becomes

$$g(u) = 2\pi a^2 J_1(u)/u$$

where

J_1 = Bessel function of order one

Normalized to the on-axis value, this equation is

$$g(u)/g(0) = 2\, J_1(u)/u$$

For a 270-foot antenna and the receiving wavelength of 5.15 inches, the value of the variable, u, at 2 degrees off axis is 68.9. This value is large enough that the Bessel function can be approximated by its asymptotic value,

$$J_1(u) \rightarrow (2/\pi u)^{1/2} \cos(u - 3\pi/4)$$

The maxima of the sidelobes occur when the cosine factor is plus or minus one, approximately. The envelope of the sidelobe maxima is given by the expression,

$$\text{sidelobe envelope} = (2/u)(2/\pi u)^{1/2}$$

At 2 degrees off axis, u equals 68.9, and this envelope expression is 0.00280 or - 51.1 db. Thus, in the ideal case, the sidelobes will be down more than 51 db at angles more than 2 degrees off axis for a uniformly-illuminated aperture of 270-foot diameter.

Tapering the illumination toward the outside edge of the antenna reduces the sidelobe levels. As an illustration, consider an illumination of the form,

$$f(r) = 1 - r^2$$

The normalized field strength pattern is then

$$g(u)/g(0) = 8\, J_2(u)/u^2$$

where

J_2 = Bessel function of order two

The asymptotic value of J_2 differs from that of J_1 only in the phase angle of the cosine factor. Thus the envelope in this case is given by

$$\text{sidelobe envelope} = (8/u^2)(2/\pi u)^{1/2}$$

At 2 degrees off axis this sidelobe expression is 0.000162 or - 75.8 db. Thus, in the ideal case, the sidelobes will be down more than 75 db at angles more than 2 degrees off axis for a 270-foot diameter antenna with the taper assumed.

Blocking the central portion of the antenna with the Cassegrain minor reflector has the effect of increasing the sidelobe levels. As an illustration, assume the same taper as above but with a blocked central region. It may then be shown that:

$$g(u)/g(0) = \left[\frac{2}{1-\delta^2}\right]^2 \left[\frac{1}{4}\Lambda_2(u) - \frac{1}{4}\delta^4\Lambda_2(u\delta) - \frac{1}{2}\delta^2(1-\delta^2)\Lambda_1(u\delta)\right]$$

where $\Lambda_p(x) = \frac{p!}{(x/2)^p} J_p(x)$

δ = relative radius of blocked area

For a 30-foot blocking reflector and a 270-foot antenna, asymptotic values cannot be used for the last two terms, since the arguments of the functions are not great enough. The first sidelobe beyond 2 degrees occurs at about 2.2 degrees. This sidelobe is down 55 db from the main beam gain. Therefore with the taper assumed, the effect of the blocking is to raise the sidelobe level near 2 degrees by 20 db.

APPENDIX H

ANTENNA NOISE TEMPERATURE

The calculation of antenna noise temperature requires knowledge of the exact pattern of the antenna as well as the inclusion of contributions from specific noise sources which may be on Earth or in the sky, such as the Sun. As an illustration, however, a simplified calculation is shown here.

Antenna noise temperature is defined by the following equation:

$$T_a = \frac{1}{4\pi} \int_0^{4\pi} G(\Omega) \quad T(\Omega) \quad d\Omega$$

where T_a = antenna noise temperature with antenna in fixed position.

Ω = solid angle

G = antenna gain function

T = temperature of noise sources

For the antenna pointing to the zenith and circular symmetric antenna and surroundings, this equation may be written (Hogg)

$$\begin{aligned} T_a &= \frac{1}{2} \int_0^{\pi} G(\theta) \quad T(\theta) \sin\theta \quad d\theta \\ &= \frac{G_o}{2} \int_0^{\theta_o/2} T_s(\theta) \sin\theta \, d\theta \\ &\quad + \frac{G_b}{2} \int_{\theta_o/2}^{\pi/2} T_s(\theta) \sin\theta \, d\theta \\ &\quad + \frac{G_b}{2} \int_{\pi/2}^{\pi} \left[a(\theta)\, T_o + \gamma(\theta)\, T_s(\pi - \theta) \right] \sin\theta \, d\theta \\ &= T_1 + T_2 + T_3 \end{aligned}$$

In expanding the equation in this form it is assumed that the antenna pattern can be represented by the constant, G_0, in the region of the main beam bounded by the cone of total angle, θ_0, and represented outside this region by the constant, G_b, which represents the side and back lobes. The temperature of the sky is denoted by T_s and that of the Earth by T_0. The quantity, a, is the power absorption coefficient of the Earth and the power reflection coefficient representing reflected sky temperature is denoted by r.

The angle, θ_0, will be assumed to include the main beam and the first few large sidelobes. Let this angle be 4 degrees, so that the region within 2 degrees of the axis is included, and assume that within this region is contained 90 percent of the transmitted power when the antenna is used for transmitting. Then

$$\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi/90} G_0 \sin\theta \; d\theta \; d\phi = 0.90$$

$$\frac{1}{4\pi}\int_0^{2\pi}\int_{\pi/90}^{\pi} G_b \sin\theta \; d\theta \; d\phi = 0.10$$

The result of the last equation is that G_b is 0.10. G_0 need not be calculated, as will be seen. In the present case, the angle, θ_0, is so small that it will be assumed that the sky temperature is constant within this angle, with the result that the main purpose of choosing a value for this angle is for the assignment of the portion of the power included and for the calculation of G_b.

Assume a sky temperature of 6°K in the zenith direction consisting of contributions from galaxy noise and atmospheric absorption. The resulting value of T_1 is

$$T_1 = T_s(0)\ \frac{G_0}{2}\int_0^{\pi/90} \sin\theta \; d\theta$$

$$= 6 \times 0.90$$

$$= 5.4^\circ \text{ K}$$

The sky temperature is nearly constant until the angle approaches 90°, the horizon, where it rises very rapidly. An approximation to this behavior is made here by assuming a temperature of 6°K up to 80° from the zenith and a constant value of 25°K between 80° and 90°. The result is

$$T_2 = 0.466°K$$

For desert land an average field strength reflection coefficient of 0.28 will be assumed. (See Reed and Russell, "Ultra High Frequency Propagation", John Wiley and Sons, Inc., Figure 4-13e, page 97). Then the power reflection coefficient is 0.0784 and the power absorption coefficient is 0.9216. For a ground temperature of 300°K,

$$T_3 = 13.85°K$$

and the total temperature is

$$T_a = 5.4 + 0.47 + 13.85 = 19.7°K$$

Due to the assumed antenna pattern in this example, the average antenna noise temperature over all pointing angles in the coverage region, which excludes angles within 10° of the horizon, is only slightly larger than the value obtained above for the antenna in the zenith direction. This is the case because the main beam region does not look at the low angles where atmospheric absorption is high nor does this region ever intercept the ground.

A lower noise temperature results when it is assumed that 95 rather than 90 percent of the power is contained within 2 degrees of the axis of the antenna. For 95 percent,

$$T_a = 5.7 + 0.23 + 6.92 = 12.9°K$$

Thus a significant reduction in noise temperature results when more of the total power is in the main beam region and less in the side and back lobes which point at the ground. Every effort will be made in the design of the antenna to reduce side and back lobes which contribute significantly to noise temperature.